

# **The Effects of Climate Change on the World's Oceans**

## **Book of Abstracts**

4<sup>th</sup> International Symposium  
June 4-8, 2018, Washington, D.C., USA

Prepared by PICES Secretariat



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## **Sessions and Workshops Descriptions**

## **Session 1: Ocean extremes and their impact on marine ecosystems**

### **Convenors:**

Thomas L. Frölicher (University of Bern, Switzerland)

Gabriel Reygondeau (Institute for the Oceans and Fisheries, The University of British Columbia, Canada)

Emanuele Di Lorenzo (Georgia Institute of Technology, GA, USA)

### **Plenary Speaker:**

Alistair Hobday (CSIRO Oceans and Atmosphere, Hobart, Australia)

### **Invited Speaker:**

Rebecca G. Asch (East Carolina University (ECU), USA)

### **Description:**

Extreme climate and weather events shape the structure of biological systems and affect the biogeochemical functions and services they provide for society in a fundamental manner. There is overwhelming evidence that the frequency, duration, intensity and timing of extreme events on land are changing under global warming, increasing the risk of severe, pervasive and in some cases irreversible impacts on natural and socio-economic systems. In contrast we know very little about how extreme events in the ocean, especially those associated with warming, acidification, deoxygenation and nutrient stress, will unfold in time and space. In addition, our understating of the impact of ocean extreme events on marine organisms and ecosystem services is very poor. This session seeks current knowledge as well as new and evolving insights into modeling and observational efforts that advance our understanding of the regional and global short-term and long-term changes in marine extreme events (heat waves, hypoxia, acidification, nutrient stress) and how these events impact marine organisms, biodiversity and ecosystem services

## **Session 2: From prediction to projection: The role of seasonal to decadal forecasts in a changing climate**

### **Convenors:**

Mark R. Payne (DTU-Aqua, Technical University of Denmark Copenhagen, Denmark)

Erica Ombres (NOAA OAR Ocean Acidification Program, USA)

Michael Jacox (University of California Santa Cruz, Institute of Marine Sciences, NOAA Southwest Fisheries Science Center, USA)

Masami Nonaka (Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, Japan)

### **Plenary Speaker:**

Lisa Goddard (International Research Institute for Climate and Society, Columbia University, USA)

### **Invited Speaker:**

Katherine E. Mills (Gulf of Maine Research Institute, Portland, ME, USA)

### **Description:**

Research examining the future impacts of environmental change and variability on ocean ecosystems has historically been focused on making projections on multi-decadal to centennial time scales. Nevertheless, recent years have seen the emergence of the first generation of marine ecosystem predictions working on shorter timescales (i.e. seasonal, annual and decadal scales). These forecasts are tailored to the tactical decision-making timescales of individuals, businesses, sectors or governments and inform strategies for coping with and adapting to climate change and variability. They also form a natural continuum with projections on the climatic timescale: many of the techniques used are similar, and testing predictability in the short-term builds confidence in our ability to project in the long-term. In this session, we welcome contributions on a broad range of potential future impacts on ocean ecosystems, including (but not limited to) ocean warming, circulation changes, acidification, eutrophication, hypoxia, and ecosystem structure or function. We seek research that addresses prediction of these ecosystem impacts as well as its relationship to long-term projections; relevant topics include 1) mechanisms that generate predictability in ocean ecosystems, 2) methods for statistically and/or mechanistically forecasting physical and/or biological variables, 3) case studies of existing biological forecast systems, 4) requirements for forecasts - including end-user needs - and assessment of forecast value, and 5) uses of forecasts within a climate-change adaptation context. Contributions that link the time-scales of prediction and projection and highlight examples of what one field can learn from the other are particularly encouraged.

### **Session 3: Carbon uptake, ocean acidification, and ecosystems and human impacts**

#### **Convenors:**

Masahiko Fujii (Hokkaido University, Japan)

Tsuneo Ono (Japan Fisheries Research and Education Agency)

Libby Jewett (NOAA)

Galen A. McKinley (Columbia University/Lamont Doherty Earth Observatory)

Nianzhi Jiao (Xiamen University)

#### **Plenary Speaker:**

Naomi Harada (RCGC, JAMSTEC, Japan)

#### **Invited Speaker:**

Nicole Lovenduski (University of Colorado Boulder, USA)

#### **Description:**

By absorbing significant quantities of CO<sub>2</sub>, the ocean provides a critical climate regulation service. At the same time, carbon uptake is altering marine biogeochemistry, food web and ecosystem properties. Other drivers of large-scale degradation of the marine environment have been widely reported, specifically temperature-driven coral bleaching and hypoxia. Yet, there exist significant uncertainties. The long-term ability of the ocean to absorb carbon and thus to modulate climate is a critical question of utmost relevance to international climate negotiations. Uncertainties with respect to impacts on marine ecosystems and human society hinders the effective management of ocean resources.

In this session, we will explore a range of physical, biogeochemical, and sociological interactions that impact the ocean CO<sub>2</sub> sink, rates of acidification, and ecosystem impacts. Presentations will characterize the physical and biogeochemical processes driving current and projected future CO<sub>2</sub> uptake, variability, and long-term trends. Advanced methods both for observing CO<sub>2</sub> uptake, and for modeling its variability and change will be discussed. Contributions are also welcome from observational, experimental, modeling and socio-economic studies on ocean acidification, hypoxia, biological carbon sequestration and related ecosystem dynamics with various spatio-temporal scales, from local to global and from short to long-term. Linkages between these processes with potential development of international observing and modeling networks, vulnerability assessments, management strategies and integrative studies are particularly welcome.



## **Session 4: Deoxygenation in Global Ocean and Coastal Waters in Relation to Climate Change**

### **Convenors:**

Denis Gilbert (Pelagic and Ecosystem Science Branch, Maurice-Lamontagne Institute, Fisheries and Oceans Canada, Québec, Canada)

Nancy N. Rabalais (Department of Oceanography and Coastal Sciences, Louisiana State University, USA)

### **Plenary Speaker:**

Dimitri Gutierrez (IMARPE, Perú)

### **Invited Speakers:**

Francisco Chavez (Monterey Bay Aquarium Research Institute (MBARI), CA, USA)

Lothar Stramma (GEOMAR Helmholtz Center for Ocean Research Kiel, Germany)

### **Description:**

Deoxygenation in the open ocean, upwelling systems, oxygen minimum zones, and coastal waters is expected to accelerate over the next decades in response to warming-induced reduction in O<sub>2</sub> solubility and increased ocean stratification that would diminish ventilation of marine waters. In addition, multiple stressors from eutrophication worsen oxygen depletion in coastal waters where hypoxia and harmful algal blooms (including those that are toxin producers) is now a prevalent and worsening situation. Observations indicate that the global ocean oxygen inventory has already decreased by 2% over the past five decades, and the volume occupied by oxygen minimum zones (OMZ) quadrupled over the same time period. Many questions are raised for open ocean and coastal waters. Do the spatial and temporal patterns of observed oxygen changes match projections from climate change models? Do large-scale patterns of atmospheric and oceanic variability such as ENSO (El-Niño Southern Oscillation), the Pacific Decadal Oscillation, the North Atlantic Oscillation or the Southern Annular Mode prevent us from detecting multi-decadal oxygen trends with confidence because of a signal to noise ratio that still remains too low? Should we expect that coastal waters, because of their adjoining landscapes and oceanscapes, will be variably affected by warming? Changes in temperature, winds and currents will alter physical processes. Biological process rates should increase up to some point where other limiting factors may intervene. Climate-driven changes in landscape use, particularly agriculture, will occur along with changes in precipitation, weather patterns, freshwater discharge and nutrient loads, all drivers of physical structure and biological production that can cause changes in dissolved oxygen concentrations in the lower water column. How does global warming affect the ocean's density stratification, vertical mixing rates, deep convection, and ventilation processes in the main thermocline? What are the expected impacts of deoxygenation on various trophic levels, on biogeochemical cycles, on fisheries and on ecosystem functions and services? How can studies of paleo-indicators shed light on what we may expect in the future?

In this session we are seeking contributions that will help address the physics and biogeochemistry of deoxygenation – from continental shelves to the deep ocean – from various angles: causes, impacts, monitoring and modeling. We welcome presentations that include long-term observations that help conceptualize the intricacies of how inter-related biological and physical processes drive oxygen changes.

**Session 5: Climate change impacts on high latitude systems on multiple scales in space and time**

**Convenors:**

William Perrie (Bedford Institute of Oceanography, DFO, Canada)

Vincent Saba (NOAA National Marine Fisheries Service, Princeton NJ, USA)

**Invited Speaker:**

Grace Saba (Rutgers University, NJ, USA)

**Description:**

This session focuses on climate impacts on high latitude systems and northern and southern polar regions at both regional (e.g., Bering Sea, Beaufort Sea, Barents Sea, Labrador Sea) and broader spatial scales (e.g., Arctic Ocean and the Southern Ocean). We seek papers that evaluate climate impacts at time scales ranging from seasonal, decadal, to multi-decadal. Included topics might be: (a) Seasonal time scales, for example, estimates of September ice conditions and links to preceding winter and early spring atmosphere or ocean conditions; (b) The impacts of climate change on high latitude and Arctic or Southern Ocean storms and their impacts and feedbacks on the upper ocean; (c) The role of inertial gravity waves, mesoscale and sub-mesoscale eddies and related processes on mixed layer depths, vertical mixing, and on the ice edge etc; (d) Estimates of climate and climate change on longer time scales, up to the next several decades, e.g. following IPCC scenarios; and (e) Climate impacts on high latitude ecosystems and ecosystem services (i.e. fisheries)

## **Session 6: The deep ocean under climate change**

### **Convenors:**

Nadine Le Bris (University Pierre and Marie Curie, France)

Andrew Sweetman (The Lyell Centre, Heriot-Watt University, UK)

### **Invited Speakers:**

Lisa Levin (Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, UC San Diego, USA)

Murray Roberts (School of GeoSciences, University of Edinburgh, UK)

### **Description:**

Covering over half of the planet, and comprising 95% its habitable volume, the deep ocean (>200 m) is critical to any analysis of the role of the ocean in climate mitigation and adaptation. Beyond its capacity to absorb excess heat, the deep ocean has a predominant role in sequestering carbon and removing it from the atmosphere. The deep sea hosts a broad range of pelagic and benthic ecosystems, which provide services that are vitally important to the entire ocean and biosphere, ranging from nutrient cycling to habitat provision, including greenhouse-gas regulation, support to biodiversity (including genetic diversity), food supply and energy production.

Today, significant changes in the environmental properties of the ocean realm in terms of water column oxygenation, temperature, pH and food supply, with concomitant impacts on deep-sea ecosystems are being recorded at great depth. Recent projections suggest that abyssal (3000–6000 m) ocean temperatures could increase by 1°C over the next 84 years, while abyssal seafloor habitats under areas of deep-water formation may experience reductions in water column oxygen concentrations by as much as 0.03 mL L<sup>-1</sup> by 2100. Bathyal depths (200–3000 m) worldwide are predicted to undergo the most significant reductions in pH in all oceans by the year 2100 (0.3 to 0.4 pH units). O<sub>2</sub> concentrations may also decline in the bathyal NE Pacific and Southern Oceans, with losses up to 3.7% or more, especially at intermediate depths. Another important environmental parameter, the flux of particulate organic matter to the seafloor, is likely to decline significantly in most oceans, most notably in the abyssal and bathyal Indian Ocean where it is predicted to decrease by 40–55% by the end of the century.

However, how these changes will affect deep-sea ecosystem (both benthic and pelagic) functions and the ecosystem services the deep sea provided are just starting to be inventoried. There are, in particular, still large gaps in our knowledge of deep hydrology, hydrography, pelagic and seafloor ecology that must be filled to anticipate how these changes may impair ecosystems at depth and potential feedbacks to surface waters. The growing imprint of human activities at great depths, including contaminant accumulation, overfishing, and disturbances from seafloor extractive activities, further justifies the need for a better understanding of how direct impacts will interact with climate stressors.

New knowledge is critical to improve predictions and assess societal impacts, and requires the expansion of deep-water observing programs with experimental capacities, to support the design of marine protected areas encompassing vulnerable regions in deep waters, and to inform environmental management of industrial activities and development of new policies addressing deep national and international waters. There is also an unprecedented need to integrate the deep ocean into ocean science and policy. New international regulations (e.g. for mining) and treaties (e.g. for biodiversity), environmental management, and spatial planning also must incorporate climate change impacts on deep ocean-processes.

In this session, we invite presentations that describe how climate stressors may alter deep-ocean ecosystems, as well as their combination with other occurring anthropogenic stressors (e.g., fishing, mineral mining), and what the possible societal implications may be. Current initiatives and observing programs, scientific and policy advances and technological developments that will contribute to this effort are also welcome.

**Session 7: Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change**

**Convenors:**

Ivonne Montes (Instituto Geofísico del Perú)

Ryan Rykaczewski (Department of Biological Sciences and Marine Science Program, University of South Carolina, USA)

**Plenary Speaker:**

Andreas Oschlies (Marine Biogeochemical Modelling at GEOMAR and the University of Kiel, Germany)

**Invited Speaker:**

Véronique Garçon (LEGOS Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, CNRS, Toulouse, France)

**Description:**

The Eastern Boundary Upwelling Systems (EBUS) are the most productive areas of the world's oceans, supporting large populations of commercially important fish species. The basic forcing mechanisms are similar across the different EBUS. However, owing to differences in the relative strengths of potential stressors, a unified understanding regarding the sensitivity of individual EBUS to climate change remains elusive. In this session, we focus on the different physical mechanisms occurring over different time scales (i.e., intradaily, intraseasonal, interannual, decadal, multidecadal) and their implications for water-column properties, biogeochemical cycles, biodiversity/ecosystem structure and functioning, and the regional climate. We seek to identify the key feedback processes in EBUS, appreciate the similarities across systems, and understand the differences. We also intend to identify critical knowledge gaps that limit our current understanding of physical and ecological responses to natural and anthropogenic climate forcing in EBUS.

## **Session 8: Understanding the impact of Abrupt Ocean Warming and Continental Scale Connections on marine productivity and food security via Western Boundary Currents**

### **Convenors:**

Ellen Mccray (NOAA / NESDIS / NCEI)

Avijit Gangopadhyay (UMassD / SMAST)

Hassan Moustahfid (FAO, UN)

John Quinlan (NOAA / NMFS / SEFSC)

### **Plenary Speaker:**

Fan Wang (Institute of Oceanology, CAS, Qingdao, China)

### **Invited Speaker:**

Hassan Moustahfid (Food and Agriculture Organization of the United Nations (FAO))

### **Description:**

Living marine resources and the coastal communities that depend on them are shifting in response to rapid physical and environmental changes. How are these changes being monitored and measured when connected on large scales by boundary currents and differing management regimes? Recent physical oceanographic studies have shown that changes in the intensity and position of several western boundary currents have already been observed. Specifically, the Kuroshio and Agulhas Currents have shifted their paths poleward. The consequences of such changes for ecosystems, and especially for marine productivity and fisheries, are beginning to emerge. The impact of Arctic meltwater and the North Atlantic Oscillation on the Atlantic Meridional Overturning Circulation and the Gulf Stream have been observed over a few decades now. These changes may be related to disappearing cod and other species from the western north Atlantic and introduction of some new species in the North Atlantic. Similar regime shifts in the productivity of several small pelagic fish species also have severe implications on food security and malnutrition of coastal communities, particularly in West Africa. This session will examine the physical and biological changes measured and documented in western boundary current regimes (e.g., Loop Current / Gulf Stream, Kuroshio, Brazil, East Australian, and Agulhas Currents), with special emphasis on how these changes impact species range shifts, phenology, species interactions, resource management planning and adaptation, as well as the food security and social fabric of coastal communities.

We welcome larger community participation from ocean, climate and fisheries scientists to present advances in (i) understanding physical and biological linkages (ii) boundary current variabilities and trends under climate change and/or (iii) the impact of recent changes in western boundary currents on marine life, productivity, fisheries and food security.

Additional emphasis will be placed on the examination of oceanic and estuarine 'hotspots' in these systems, and any evidence for specific areas that can provide environmental refugia for living marine resources.

**Session 9: Drifting into the Anthropocene: How will pelagic marine ecosystems be affected and what are the biogeochemical and lower trophic consequences**

**Convenors:**

Todd O'Brien (NOAA Fisheries, USA)

Angelica Peña (Institute of Ocean Sciences, Canada)

**Invited Speaker:**

Laura Lorenzoni (Ocean Biology and Biogeochemistry Program (OBB), NASA Headquarters Science Mission Directorate)

**Description:**

Climate-related changes in the physical and chemical oceanic environment impact the biological and biogeochemical components of marine ecosystems. These impacts take effect at a variety of spatial and temporal scales, and at varying magnitudes, and often differ greatly between geographic regions and realms (e.g., polar vs. equatorial, shelf vs. open ocean). Ultimately, these changes can greatly alter the productivity, biodiversity, and resilience of the marine ecosystems that depend on them.

Since the first ECCWO in 2008, numerous studies have documented changes in ocean acidification, deoxygenation and carbon cycling, planktonic biodiversity and biogeographic range, and the phenology and strength of seasonal events (e.g., spring blooms, onset and strength of stratification, extent and presence of sea ice). Have these instances and impacts changed in magnitude, severity, or geographic extent since 2008, and are new impacts and side-effects now being uncovered?

This session will look at observed and predicted causes and impacts of climate-related changes within pelagic marine lower trophic levels (e.g., microbes, plankton, larval fish) and biogeochemical components (e.g., carbon, oxygen and nutrient cycling), including studies using systematic and sustained ocean observations and modeling.

## **Session 10: Management and Conservation of Species on the Move**

### **Convenors:**

Charles Stock (USA)

Shin-ichi Ito (Japan)

Thomas Therriault (Canada)

Wendy Morrison (USA)

Samantha Twiname (Australia)

### **Plenary Speaker:**

Gretta Pecl (IMAS, CMS, Tasmania, Australia)

### **Invited Speakers:**

Jorge García Molinos (Arctic Research Center, University of Hokkaido, Sapporo, Japan)

Malin Pinsky (Rutgers University, NJ, USA)

### **Description:**

Most fisheries and marine conservation efforts have been managed under the assumption that species distributions are static or fluctuate around historical averages. Sustained scientific surveys and new technologies, however, have revealed persistent climate-driven movements. In some areas, this has resulted in movements across management jurisdictions. Such movements are projected to continue under global warming, creating difficult questions for managers trying to balance coastal economic interests and conservation goals. For example, do past observed shifts reflect future responses? How will the invasion of new species impact resident populations? How will shifted species adapt to new environments? When should new fisheries be established? When is a historically productive fishery extirpated? Should protected areas be relocated? How should historical quotas be adjusted for range shifts? This session welcomes ecosystem, policy and economic research aimed at answering such questions and developing management and conservation strategies that are resilient to movement. Contributions can span research addressing novel observations of and mechanisms underlying movement, modeling historical and projecting future movements and their ecosystem consequences, and incorporation of movement into management and conservation decisions.

**Session 11: Benthic and pelagic system responses in a changing ocean: From genes to ecosystem level functioning**

**Convenors:**

Mahasweta Saha (Helmholtz Center for Ocean Research - Kiel (GEOMAR), Germany)

Stacy Krueger Hadfield (University of Alabama at Birmingham, USA)

Ulrich Sommer (Helmholtz Center for Ocean Research - Kiel (GEOMAR), Germany)

**Plenary Speaker:**

Steve Widdicombe (Marine Ecology and Biodiversity, Plymouth Marine Lab, UK)

**Invited Speaker:**

Ulrich Sommer (GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany)

**Description:**

The rapid climate change we are experiencing today poses a major threat to Earth's biodiversity and ecosystem functioning. Ongoing global change is expected to shift the average levels of pCO<sub>2</sub>, temperature, pH or oxygen by regionally-variable amounts and also to increase the occurrence and intensity of transient extreme events causing species extinction and range shifts with economic impacts. It has recently been suggested that increased variation, rather than changes in mean values, may represent the greater threat to species survival, stressing the need to experimentally study the effects of both environmental variations and extreme events on ecosystems and their functioning. Along with overfishing and deoxygenation at local scales, biological invasions form one of the principal components of global change. Disease occurrence (pathogens, parasites) among hosts including algae, corals and sponges can substantially increase with ocean warming. This session invites contributions from marine biologists and ecologists to bring diverse expertise and new perspectives to a subject of global significance. We encourage submissions from field, laboratory, and mesocosm studies that offer new insights into the functioning of benthic and pelagic ecosystems at the genetic, population, community and ecosystem scale under biotic and abiotic stressors.



## **Session 12: Scenarios and models to explore the future of marine coupled human-natural systems under climate change**

### **Convenors:**

William W. L. Cheung (Institute for the Oceans and Fisheries, The University of British Columbia, Canada)

Lisa Crozier (Northwest Fisheries Science Centre, NOAA, USA)

Desiree Tommasi (Southwest Fisheries Science Centre, NOAA, USA)

Oai Li Chen (Institute for the Oceans and Fisheries, The University of British Columbia, Canada)

### **Plenary Speaker:**

Eric D. Galbraith (Universitat Autònoma de Barcelona, Spain)

### **Invited Speaker:**

Kirstin Holsman (NOAA Alaska Fisheries Research Center, Seattle, USA)

### **Description:**

The oceans consist of coupled human and natural systems. Responses of marine ecosystems to climate change are thus shaped by human-natural interactions. For example, climate change effects on the biogeochemical properties of the oceans and foodwebs set ecological constraints on fish production. Economically, seafood demand from the growing population, evolving consumption patterns and costs of seafood production determine the viability of fisheries and aquaculture. Socially, available technology, historical development, political stability and regulatory policies also limit the extent of fisheries and mariculture development. Developing scenarios and models for the oceans that incorporate interactions between human and natural components are essential for understanding the dynamics of these coupled systems and informing climate mitigation and adaptation choices. This session invites oral or poster presentations that contribute to understanding the interactions between human and natural marine systems under climate change. Specific topics of the submissions may include, but are not limited to, scenarios e.g., shared socioeconomic pathways for marine systems or sectors; models that integrate different dimensions of human-natural systems e.g., biophysical, economic, social, political dimensions; management strategy evaluations e.g., stakeholder-driven simulation processes that incorporate biological, fishery, and management sub-models to compare the effectiveness of alternative regulatory policies while accounting for uncertainty in different sources, including climate effects; testing, comparison, exploration and integration of multiple modelling approaches; and empirical and mechanistic exploration of the dynamics of coupled human-natural systems. Studies from different marine systems, sectors and spatial scales are welcome. A special issue of a journal for this session may be organized.

## **Session 13: Multiple stressors at multiple scales: ecosystem based management in the face of changing ocean conditions**

### **Convenors:**

Carol Robinson (University of East Anglia, UK)

Isaac Kaplan (NOAA North West Fisheries Science Center, USA)

Franklin Schwing (Office of Science and Technology, NOAA Fisheries, USA)

Philip Boyd (University of Tasmania, Australia)

Saskia Otto (Hamburg University, Germany)

### **Plenary Speaker:**

David Allen Hutchins (University of Southern California, Los Angeles, CA, USA)

### **Invited Speaker:**

Sarah Cooley (Ocean Acidification Program, Ocean Conservancy, Washington DC, USA)

### **Description:**

The marine realm is experiencing unprecedented changes resulting from the complex interactions between multiple stressors and drivers over multiple time and space scales and which, in turn, affect the human communities that rely on the ocean's services and resources. Ocean warming, acidification, changing circulation, and deoxygenation are all expected to shift both the productivity and distribution of marine species, and therefore their availability to human communities that depend upon them.

Ecosystem-based management (EBM) is an integrated science-based approach to help evaluate trade-offs in resource uses and maintain healthy, productive, and resilient ecosystems and the services they provide. EBM recognizes the full array of ecosystem interactions and components, including humans, and because it is adaptive, EBM allows the dynamic nature of ecosystems to be managed in the face of multiple human and natural stressors. Integrated ecosystem assessments (IEAs) are a critical science-support element enabling EBM. IEAs synthesize biological, environmental, and socioeconomic information, define objectives, monitor the status of indicators related to those objectives, assess risk, test alternative management scenarios and options, and measure performance relative to objectives. This holistic approach allows consideration of trust resources (e.g., protected species, fish stocks) and trade-offs across multiple human sectors such as shipping, fishing, and energy in the context of stressors such as warming and ocean acidification.

This session invites contributions from researchers investigating how interactions between climate-driven stressors such as warming, ice loss, ocean acidification, and deoxygenation and human driven stressors such as fishing, coastal development, and pollution, impact marine ecosystem structure and functioning at a range of scales, including the provision of ecosystem services. This includes analyses of the ecosystem consequences of multiple stressors on individual species and the importance of biodiversity in the resilience of ecosystems in the face of multiple drivers of change. Examples of integrated sectoral management such as ecosystem-based fisheries management (EBFM), an important step toward cross-sector EBM, are requested. Studies that project and predict future states by incorporating the estimated consequences of interacting multiple stressors at multiple scales on marine ecosystems and human societies, and those that describe how governments and partners are incorporating climate-related impacts into management and decision-making with the use of EBM tools, approaches, and case studies are also encouraged.

The session is aligned with the 2015-2026 science plan of the SCOR (Scientific Committee on Oceanic Research) and Future Earth sponsored Integrated Marine Biosphere Research (IMBeR) project and the SCOR working group 149 'Changing Ocean Biological Systems'.

## **Session 14: Vulnerability and adaptation of marine socio-ecological systems to climate change**

### **Convenors:**

Jörn Schmidt (Kiel Marine Science at Kiel University, Kiel, Germany)

Catarina Santos (MARE — Marine and Environmental Sciences Centre, Laboratório Marítimo da Guia, Faculdade de Ciências, Universidade de Lisboa, Cascais, Portugal)

Katherine E. Mills (Gulf of Maine Research Institute, Portland, USA)

### **Plenary Speaker:**

Merle Sowman (University of Cape Town (UCT), South Africa)

### **Invited Speaker:**

Elizabeth Fulton (CSIRO Oceans and Atmosphere)

### **Description:**

The recent OECD report on the blue (ocean) economy identified it as being “essential to the welfare and prosperity of humankind” and “a key source of food, energy, minerals, health, leisure and transport upon which hundreds of millions of people depend.” With ocean economic activity poised to double by 2030, operations and management of existing and emerging industries will need to function effectively in a changing climate to ensure the sustainability of both socioeconomic development and ocean ecosystems.

Climate change is already profoundly affecting coastal communities, as well as ocean-based livelihoods and industries (e.g. fisheries, aquaculture) and related management systems, through a variety of impact pathways (e.g. sea level rise, ocean acidification, extreme events, species distribution shift). Adaptation approaches that have occurred in response to such climate-related impacts vary widely across topics and geographic regions. Similarly, planning for future resilience and adaptation has progressed differently across management bodies, communities, and industries.

Efforts to understand the impacts of climate change, and to plan for future adaptation strategies and management approaches, require a recognition and understanding of existing linkages and feedbacks between (and within) social and ecological factors. In this session, we seek contributions that address frameworks or case studies from around the world on sustainability in marine socio-ecological systems under a changing climate. In particular, we welcome contributions that advance the understanding and awareness of: (1) dimensions of vulnerability (e.g. physical, biological, human, financial) that affect adaptation and mitigation approaches; (2) tools and approaches for planning under climate change (e.g. trade-off analyses, evaluations of robustness of different management approaches, vulnerability assessments); and (3) climate adaptation efforts (both already implemented or planned). Contributions may span multiple social and institutional scales (e.g. individuals, communities, industries, management bodies). Examples related to marine spatial planning (MSP) and fisheries are of particular interest, but a wider range of topics is welcome to the session, specifically studies developed at a community scale (e.g. community-level adaptation to climate change in developing countries)

Besides oral contributions, we specifically invite the presentation of case studies as posters, with a short elevator pitch (max. 2 minutes) in the session. A concise session report with best practices and case studies will be produced.

**Session 15: Fisheries and aquaculture in the face of climate change: Current actions, identified solutions and opportunities in support of sustainable livelihoods and food security**

**Convenors:**

Lena Westlund (FAO Fisheries and Aquaculture Department)

Hassan Moustahfid (FAO Fisheries and Aquaculture Department)

Anthony Charles (IUCN Fisheries Expert Group (IUCN-CEM-FEG) and the Community Conservation Research Network (CCRN))

Melinda Agapito (Memorial University of Newfoundland, Canada)

Cyrille Barnerias (Global Environment Facility (GEF))

Florence Poulain (FAO Fisheries and Aquaculture Department)

Michael Rust (Department of Commerce, National Oceanic and Atmospheric Administration (NOAA))

**Plenary Speaker:**

Prateep Kumar Nayak (University of Waterloo, ON, Canada)

**Invited Speaker:**

Abdelmalek Faraj (National Institute of Fisheries Research, Morocco)

**Description:**

As climate change impacts are threatening marine and inland water ecosystems, fishers, fish farmers and coastal inhabitants will bear the full force of these impacts through less stable livelihoods, changes in the availability and quality of fish for food, and rising risks to their health, safety and homes.

This session will showcase current solutions and opportunities (good practices, tools and approaches) for how to respond to climate change and disaster risks in the fisheries and aquaculture sector. In particular, presentations on initiatives and adaptive strategies that use the Ecosystem Approaches to Fisheries and Aquaculture are welcomed as well as those that are concerned with the context of small-scale fishing and fish farming communities, including with reference to Chapter 9 on Disaster risks and climate change of the Voluntary Guidelines for securing sustainable small-scale fisheries in a context of food security and poverty eradication (the SSF Guidelines – FAO, 2015). In this spirit, the session will consider (i) holistic and integrated approaches to address disaster risks and climate change, (ii) the human rights based approach to development (on which the SSF Guidelines are based), (iii) policies, strategies and initiatives for adaptation, mitigation and resilience-building that are developed in full consultation with fishing and fish farming communities, including indigenous peoples and both men and women.

## **Session 16: Climate, Oceans and Security**

### **Convenors:**

Apurva Dave (US Global Change Research Program, USA)

Alice Alpert (U.S. Department of State, USA)

### **Invited Speaker:**

Frances A. Ulmer (US Arctic Research Commission (USARC), USA)

### **Description:**

The marine environment supports livelihoods and provides sustenance and essential services to communities, economies and nations around the world. As climate change affects ocean systems, augmenting and amplifying other environmental stresses, it also impacts human systems that rely on the oceans. While the socio-economic dimensions of these impacts have received more mainstream attention, a broad awareness of how ocean change could affect international governance, political and social stability, and military readiness, operations and strategy, is only recently emerging.

The purpose of this session is to explore how climate impacts on the oceans will, and in some cases already have, affect human, national and international security. We welcome submissions exploring a wide range of issues- including how climate impacts might challenge regional and global governance frameworks (for example, through loss of sea ice in the Arctic or shifts in fish stocks in the South China Sea), pose risks to military effectiveness (for example, through sea level rise around coastal infrastructure), or undercut investments in development (for example, through extreme events that disrupt societies and strain humanitarian assistance). We also welcome papers that examine strategically important regions in which multiple security issues overlap.

This session is intended to promote exchange across ocean science and security policy disciplines, and so a particularly important area of discussion will be the research needs for addressing security issues. The session will also identify gaps in our current knowledge and policy frameworks, and will advance understanding of both the vulnerability and resiliency of security- of the associated challenges and opportunities- arising from oceanic and climate change.

**Session 17: Effects of climate change on ocean ecosystem health: Projecting occurrences of harmful algal blooms and disease outbreaks and assessment of the risk to ecosystem functioning, aquaculture, fisheries and human health**

**Convenors:**

Elisa Berdalet (Institut de Ciències del Mar -CSIC-, Barcelona, Spain)

Ryan Carnegie (Department of Aquatic Health Sciences, Virginia Institute of Marine Science, College of William & Mary, VA, USA)

Alexandra Campbell (Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Australia)

Kedong Yin (School of Marine Sciences, Sun Yat-Sen (Zhongshan) University, Guangzhou, China)

**Plenary Speaker:**

Iddya Karunasagar (Nitte University, Mangalore, India)

**Invited Speaker:**

Xuelei Zhang (First Institute of Oceanography (FIO), State Oceanic Administration, China)

**Description:**

Human and ocean health depends on the sustainable use of marine ecosystems, which host invaluable organisms biodiversity, supply food and support economic activities (fisheries, aquaculture, tourism, recreation). These benefits have always been threatened by natural phenomena such as harmful algal blooms (HABs) and pathogen diseases affecting marine life and ecosystems and producing toxins that are bioaccumulated and transferred through the food web up to humans. However, ongoing climate change and anthropogenic pressures can exacerbate these negative impacts by favoring geographic expansion of HAB organisms and increasing the frequency and intensity of their outbreaks, and by fostering pathogen diseases of marine resource species.

Designing effective strategies to protect human health, societal and marine environmental impacts of HABs and marine diseases requires among others, improving the fundamental knowledge of the mechanisms driving these events and consistent and long-term data series. In particular, there is a need to understand how changes in the main drivers of primary producers (surface water temperature and salinity, ocean stratification, wind and water circulation patterns, precipitation-linked nutrient inputs) combined with anthropogenic pressures on aquatic ecosystems (surface water acidification, alteration of natural habitats) could stimulate HAB occurrence and marine diseases in fisheries, aquaculture and marine life in general.

This session is aimed to summarize the existing understanding and gaps of knowledge about the future trends of the noxious events and their risks to aquaculture, fisheries and human and ecosystems health. The session has a transdisciplinary scope addressed to scientists, stakeholders, policymakers, and the public to find joint strategies to manage, mitigate and adapt to the impacts of these events in the future.

## **Session 18: Coastal ecosystem and their blue carbon science, conservation and policy progress**

### **Poster Session only**

#### **Convenors:**

Jorge Ramos (Conservation International)

Kirsten Isensee (IOC-UNESCO)

Dorothee Herr (IUCN)

#### **Plenary Speaker:**

Severino G. Salmo III (Department of Environmental Science, Ateneo de Manila University, Quezon City, Philippines; Visiting Foreign Researcher at the Tropical Biosphere Research Centre of the University of the Ryukyus, Okinawa, Japan)

#### **Description:**

Coastal and Marine Ecosystems (CMEs) - such as mangroves, tidal marshes, and seagrass meadows - mitigate the effects of climate change by sequestering carbon dioxide (CO<sub>2</sub>) into the vegetation and their surrounding soil from the atmosphere and oceans. CMEs also sequester carbon (blue carbon) at significantly higher rates than terrestrial forests and store three to five times more carbon per equivalent area than tropical forests. Accounting for the blue carbon sequestered in coastal ecosystems and the emissions resulting from ecosystem conversion has the potential to be a significant tool in promoting and sustainably financing marine management and conservation. Recently, there has been a rapid expansion of such blue carbon focused policy and management programs and opportunities from local to global scales largely resulting from ongoing development of coastal carbon research and synthetic science. For example: 1) advances through the Verified Carbon Standard now facilitates coastal wetland restoration projects access financing through voluntary carbon markets; 2) The 2013 Wetlands Supplement to the IPCC 2006 Guidelines for National Greenhouse Gas Inventories includes guidance for countries on integrating coastal blue carbon systems into their national GHG inventories; 3) a rapidly expanding portfolio and interest of coastal conservation and REDD+ projects globally focused in part on blue carbon; and 4) inclusion of coastal wetlands in countries national climate change commitments. A number of key scientific and technical issues related to carbon assessments and mapping, land use driven emissions, climate change and sea level rise impacts on coastal carbon budgets and carbon monitoring remain to be discussed. Here we describe recent blue carbon conservation and policy progress and the science research and tools that will be needed in the near future to support the protection and restoration of these ecosystems and with their climate change mitigation ecosystem service.

## **Workshops**

### **Workshop 1: Communicating and responding to climate change**

#### **Convenors:**

Bryony Townhill (Cefas, UK)

Paul Buckley (Cefas, UK)

John Pinnegar (Cefas, UK)

#### **Invited Speaker:**

Hazel Oxenford (Centre for Resource Management and Environmental Studies (CERMES), University of the West Indies (UWI), Centre for Resource Management and Environmental Studies (CERMES), Barbados)

#### **Description:**

Duration: 1-day workshop

This workshop focusses on the translation of research outputs into practicable actions that citizens and stakeholders can take to respond to climate change in the marine environment. If governments, industries, marine managers and members of the public are to take notice and put in place successful adaptation actions in the future, it is vital that the results of climate change research are effectively communicated to wider audiences outside of academia. Talks are welcome on initiatives that aim to bring together scientific information for a broad audience, to translate complex ideas and information into products that are useful to decision makers and practitioners. Also talks on the development of practical and applied approaches to risk assessment, adaptation implementation and building resilience of the marine environment and coastal communities.



## **Workshop 2: Advances in Earth System Models (ESMs) for marine applications**

### **Convenors:**

Jasmin John (NOAA/GFDL, USA)

Takashi Mochizuki (JAMSTEC, Japan)

Michael Alexander (NOAA/ESRL, USA)

### **Invited Speaker:**

Matthew Long (Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, Colorado, USA)

### **Description:**

Duration: 1-day workshop

Global climate and earth system projections contributed to the Coupled Model Intercomparison Project (CMIP) have been pivotal in building our understanding of the potential impacts of climate change on oceans, marine ecosystems, and marine resources. Progress, however, has also been hindered by numerous model limitations. These include coarse grid resolution and uncertainties in (or limited resolution of) climate and earth system dynamics. The upcoming sixth phase of CMIP seeks to advance global climate and earth systems models through an internationally coordinated set of experiments by incorporating both a standard set of idealized and historical simulations as well as a broad suite of Model Intercomparison Projects (MIPs), which will be of particular importance to the ocean science and marine ecosystem communities to advance understanding of ocean physics and biogeochemistry, and their role in climate processes, variability, future change, and impacts. The goal of this workshop is to share and exchange information on new and innovative ocean physical, biogeochemical, and ecological model developments and formulations incorporated into CMIP6 models and simulations and their relevance to marine applications. In particular, we invite submissions from colleagues across the international community describing CMIP6 model advances contributing to process understanding of climate and earth system change, variability, and predictability on broad timescales. Objectives of the workshop are to share the state-of-the-science in earth system model development between the earth system modeling and impacts communities, prioritize remaining modeling challenges to bridge understanding between these communities, and identify opportunities for synergistic collaborations.

### **Workshop 3: Exploring potential ocean-based solutions to climate change impacts on marine biodiversity and ecosystem services**

#### **Convenors:**

William W. L. Cheung (Institute for the Oceans and Fisheries, The University of British Columbia, Canada)

Elizabeth McLeod (The Nature Conservancy, Arlington, USA)

Fiorenza Micheli (Hopkins Marine Station, Stanford University, USA)

Colette Wabnitz (Institute for the Oceans and Fisheries, The University of British Columbia, Canada)

#### **Invited Speaker:**

Ling Cao (Center on Food Security and the Environment, Stanford, CA, USA)

#### **Description:**

Duration: 1-day workshop

Marine biodiversity and ecosystems are now at a crossroads and the world is demanding effective solutions to mitigate and adapt to climate change to maintain natural services provided by the ocean. Therefore, this workshop will focus on exploring and examining potential ocean-based solutions to “avoid the unmanageable” and to “manage the unavoidable” risks from climate change on marine biodiversity and ecosystem services. These potential solutions may include mitigation and adaptation measures, nature- or technology- based, as well as for local and global scales.

Specifically, the workshop aims to discuss about the potential effectiveness of proposed or implemented solution options to moderate climate impacts, challenges and opportunities for their implementation, their implications for sustainable development, as well as research and policy agenda to make progress in meeting these challenges. The workshop will be multi-disciplinary (from natural to social sciences) and welcome the participation from academics, practitioners (e.g., international, government or non-governmental organizations) and private sectors (e.g., fishing, aquaculture, tourism). The workshop will include short presentations and group discussions. Specific outcomes will include a manuscript that is based on the discussion and findings of the workshop, and a proposal for a working group to further discuss the research and policy agenda identified from this workshop.

**Workshop 4: Climate change adaptation of fisheries and aquaculture: examples of field projects supporting countries and communities**

**Convenors:**

Tarub Bahri (FAO), Amber Himes-Cornell (FAO), Iris Monnereau (FAO)

**Invited Speaker:**

Edward H. Allison (College of Environment, University of Washington, USA)

**Description:**

Duration: 1/2 day workshop

The workshop will present a series of field projects led by the Food and Agriculture Organization and other partners to support countries and fisheries-dependent communities adapt to climate change. The presentations will address different angles linking physical environment to social, economic and institutional aspects of climate change adaptation in different regions of the world (Caribbean, Africa, Asia, Latin America and Europe). They will also describe relevant tools and measures that can support adaptation. The workshop will be the opportunity to provide details about field projects and gather scientific and methodological inputs from the participants. Eventually, the workshop is expected to contribute to a major understanding of both the enabling conditions of adaptation and its main challenges.

## **Workshop 5: Climate Change and Fishing Communities: Interactions with Environmental Conservation, Sustainable Livelihoods and Food Security**

### **Convenors:**

Anthony Charles (Community Conservation Research Network & Senior Research Fellow, Saint Mary's University Canada)

Daniela Kalikoski (Strategic Programme on Rural Poverty Reduction, FAO of the UN Italy)

Jessica Sanders (Fisheries and Aquaculture Department, FAO of the UN Samoa)

Lena Westlund (Fisheries and Aquaculture Department, FAO)

### **Invited Speakers:**

Mohammad Mahmudul Islam (Sylhet Agricultural University, Bangladesh)

Jake Rice (Emeritus, Fisheries and Oceans Canada (DFO))

### **Description:**

Duration: 1-day workshop

This workshop examines how climate change both drives and exacerbates the multi-level imperatives of livelihood sustainability, food security and associated initiatives of community-based environmental conservation, within coastal fishing communities globally. Within that context, the workshop also explores the types of governmental and international programs and policies needed to effectively engage with and support small-scale fishery and coastal community stewardship and security, in the face of climate change. These goals will be met by drawing on experiences of three major international bodies – the FAO, the IUCN and the Community Conservation Research Network – around climate change interactions with fisheries and coastal communities.

The first phase of the workshop will focus on the main theme: “Insights and Priorities for Linking Climate Change with Environmental Conservation, Sustainable Livelihoods and Food Security: A Fishing Communities Perspective”. The theme will be explored through scene-setting presentations (by the convenors), invited presentations (Islam and Rice) and contributed presentations, collectively drawing on a range of scientific, practice and policy perspectives, together with discussion sessions in which participants are invited to share ideas and practical experiences.

The second phase of the workshop, in the afternoon, will focus on the interactions of poverty and climate change in the context of coastal communities, coastal areas and Small Island Developing States (SIDS). A participatory process will be followed to generate ideas, insights and priority directions relating to the interaction of climate change with poverty. This will provide input into a current initiative of the Food and Agriculture Organization of the UN to explore desired pathways to make progress on linking poverty reduction and climate change responses. An initial presentation will set the scene for discussion of the topic, and then each participant will be invited to share their perspectives. The workshop will culminate in generating a set of recommendations for effective approaches to linking climate responses and poverty reduction.

## **Workshop 6: Utilizing bioenergetics measurements and modeling to evaluate climate change effects on marine species and ecosystems**

### **Convenors:**

Myron Peck (Center for Earth System Research and Sustainability (CEN), University of Hamburg, Germany)

Kirstin Holsman (NOAA NMFS Alaska Fisheries Science Center, USA)

Janet Nye (School of Marine and Atmospheric Sciences, Stony Brook University, USA)

### **Invited Speaker:**

Kenneth A. Rose (Horn Point Laboratory, University of Maryland, Center of Environmental Science, USA)

### **Description:**

Duration: 1-day workshop

Climate-driven changes in the mean, variance and interaction of key abiotic factors (e.g. water temperatures, extents of hypoxia, decreases in pH) will directly impact the distribution, fitness and abundance of species as well as alter energetic demands of consumers with reciprocal impacts on the food web. These effects are expected across all marine habitats and may be particularly pronounced at high latitudes. A physiological-based (cause-and-effect) understanding of the mechanisms underlying changes in the distribution, reproduction, and growth of fish is paramount for projecting the effects of climate change on these living marine resources as well as the knock-on (e.g. trophodynamic) effects at the community and ecosystem levels.

Advancements in bioenergetics-based modeling such as the inclusion of key physiological processes within individual-based, mass-balance, and ecosystem/food-web models, have provided a suite of tools for quantifying climate-driven changes in the distribution, abundance and productivity of fish stocks. For example, stage-specific and/or seasonal changes in the storage and allocation of food energy to growth and/or reproduction are depicted in dynamic energy budget models. These bioenergetics-based approaches can inform advice on the management of marine species and habitats under future climate change if outputs are deemed robust and can be incorporated within socio-economic models and management frameworks. The usefulness of these modelling tools depends, to a great extent, on structural assumptions and parameter estimates used to depict physiological and behavioural responses to changes in the mean, variance and interaction of key, abiotic factors and socio-economic drivers.

This workshop will include short presentations and discussion to (1) review state of knowledge on the effects of multi-stressor effects on vital rates (growth, feeding, survival, reproduction) of fish and the ability of bioenergetics-based models to capture observed patterns, (2) identify data requirements needed to better parameterize existing models for near-term forecasts and long-term projections (from single- to multi-species and ecosystem/end-to-end, and (3) discuss methods and case-studies for integrating the outputs gained from these bioenergetics-based models into biological ensembles and/or social-ecological system models and marine management frameworks. A review paper is planned on these topics.

## **Workshop 7: What do seabirds reveal about the effects of climate change on the World's Oceans?**

### **Convenors:**

William J. Sydeman (USA)

John F. Piatt (USA)

Yutaka Watanuki (Japan)

Joël Durant (Norway)

Robert Crawford/Lynne Shannon (South Africa)

### **Invited Speakers:**

Kate R. Searle (NERC Centre for Ecology and Hydrology, Edinburgh, UK)

Richard B. Sherley (Environment and Sustainability Institute, University of Exeter and Bristol Zoological Society, UK)

### **Description:**

Duration: 1-day workshop

Seabirds are the most conspicuous marine organisms living at the interface of the atmosphere and the ocean, and due to sustained public interest, have been extremely well-studied for multiple decades at many key locations around the world. The information base on seabirds is thus rich and comprehensive, with substantial longevity. Recent reviews and meta-analyses indicate complex — often unexpected — responses of seabirds to various manifestations of climate change. When combined with concurrently collected data on local food fish stocks and fisheries, these same datasets have provided strong insights into the functional and numerical relationships between climate change, meso-predators, and prey, and therefore provide unique benchmarks for global climate impacts assessments. In this workshop, we seek to compare marine bird response to climate change across marine ecosystems and biomes, from the tropics to the Arctic and Antarctic, develop a mechanistic understanding of these responses, with an emphasis on connections between climate change and the availability of seabird prey (forage fish and crustaceans), and educate informed laypeople (including managers and policy-makers) of recent observations of apparent marine bird responses to climatic factors globally, including unprecedented massive seabird die-offs in many parts of the world. We anticipate two primary scientific products from this effort: (a) publication of a multi-authored volume based on the workshop in a speciality journal (e.g., *Marine Ecology Progress Series* or *Global Change Biology*), and (b) a comprehensive synthesis summarizing the state of knowledge concerning seabirds and climate interactions globally designed for a high impact journal (*Science* or *Nature*).

## **Workshop 8: Connecting climate, ocean and ecosystem observation – Ocean observation futures**

### **Convenors:**

Jörn Schmidt (Kiel Marine Science at Kiel University, Kiel, Germany)

Sabrina Speich (Department of Geosciences, Ecole normale supérieure, Paris, France)

Fred Whoriskey (Department of Biology, University of Dalhousie, Halifax, Canada)

Daniele Iudicone (Stazione Zoologica Anton Dohrn, Naples, Italy)

John A. Barth (Marine Studies Initiative, Oregon State University, Corvallis, USA)

### **Invited Speaker:**

Douglas Wallace (Dalhousie University and Ocean Frontier Institute)

Patricia Miloslavich (University of Tasmania, Hobart, Australia)

### **Description:**

Duration: 1-day workshop

In the face of a changing ocean, we need to adjust our ocean observation systems to meet new needs. What do we need to know about the ocean-human system and what data do we need to collect to increase our knowledge and better manage its future development?

The workshop will bring together different ocean related observation communities to discuss the current capacities of each community, and how each foresees the future. Topics will include where we are in observing climate, ocean, eco- and human system related processes and variables, and how we are integrating across systems; what are climate, ocean, eco- and human system related objectives; what are major societal needs that the observing systems are addressing (e.g. ocean warming, changing dynamics, plastic litter, acidification, noise, overharvesting, biological observation); where do we need to adapt from where we are to achieve these goals; What are the major obstacles and what are the stepping-stones?

The workshop will address different levels of connectivity across technology levels, different disciplines, different temporal and spatial scales, different needs of stakeholders and the connectivity between national funding agencies and institutions.

It will not only address observational needs, but also the related research data infrastructure needs to connect data across all these levels including practical issues like standards and formats.

The product of the workshop will be a vision paper in a peer-reviewed journal and a one page summary for policy makers.

**Workshop 9: Vulnerability of Low Elevated Coastal Zones (LECZ) to SLR in changing oceans**

**Convenors:**

Tarek M. El-Geziry (National Institute of Oceanography & Fisheries (NIOF), Alexandria, Egypt)

Sathaporn Monprapussorn (Department of Geography, Faculty of Social Sciences, Srinakharinwirot University, Bangkok, Thailand)

**Invited Speaker:**

Mohamed Abdel-Karim Aly Abdrabo (University of Liverpool, UK)

**Description:**

Duration: 1-day workshop

With a changing climate, sea level is also changing. The sea level rise issue is a critical issue, especially for the Low Elevated Coastal Zones (LECZ) worldwide. This workshop aims to focus on the impacts of the SLR on the LECZ, the vulnerability of these areas to the projected SLR rates, the related socioeconomic issues, in addition to the coastal risk factor and design.



## **Workshop 10: Intercomparison of fisheries and marine ecosystem models**

### **Convenors:**

Olivier Maury (IRD, France)

Derek Tittensor (UNEP-WCMC, Dalhousie University, Canada)

Heike Lotze (Dalhousie University, Canada)

Eric D. Galbraith (Universitat Autònoma de Barcelona, Spain)

Tyler Eddy (University of British Columbia, Canada)

### **Invited Speaker:**

Eric D. Galbraith (Universitat Autònoma de Barcelona, Spain)

John Pinnegar (Centre for Environment, Fisheries & Aquaculture Science, UK)

### **Description:**

Duration: 1-day workshop

The Fisheries and Marine Ecosystem Model Intercomparison Project (FISH-MIP) is a component of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP). This workshop will gather ecosystem modelers contributing or interested to contribute to FishMip. Contributing models will be presented in detail and a typology will be drawn, based on theoretical underpinnings and numerical implementations. The first round of projections will be discussed in light of model's characteristics. New developments as well as future analyses will be discussed, including the use of socio-economic scenarios (typically SSPs) for forcing fisheries models. A simulation protocol combining the use of RCPs and SSPs will be established.

## **Workshop 11: Quantifying thresholds in driver-response relationships to identify reference points**

### **PICES Working Group 36 (CERP) workshop**

#### **Convenors:**

Mary Hunsicker (USA)

Robert Blasiak (Sweden)

Elliott Hazen (USA)

Jennifer Boldt (Canada)

Xiujuan Shan (China)

#### **Description:**

Duration: 2-day workshop

Marine ecosystems are influenced by dynamic atmospheric and oceanographic drivers and human activities. An open question is whether biological responses within the ecosystems are linear or nonlinear in relation to climatic forcing variables or the abundance of other species. Strong nonlinearities indicate the existence of thresholds beyond which small changes in a climatic variable or species abundance cause large responses in another ecosystem component. Thus, knowledge of where these thresholds exist is valuable for determining target or limit reference points to prevent ecosystem components from tipping into undesirable states.

The CERP: Common Ecosystem Reference Points across PICES Member Countries is working group (WG36) of PICES. During Day 1 of the workshop, the PICES working group members will review and make progress on Terms of Reference (TOR) (see WG-36 webpage), specifically identifying the focal ecosystems and indicators for our WG (TOR 2), the available data sets (TOR 2), the methods selected for identifying thresholds in the ecosystem indicators (TOR 3), and applying analyses to focal ecosystems and indicators (TOR 4).

Day 2 of the workshop is open to any ECCWO participants that wish to attend and contribute to (or learn more about) the topic of quantifying thresholds for identifying reference points. The goals of Day 2 are to 1) review and learn from similar efforts from other organizations such as ICES working groups and IndiSeas and 2) identify potential partnerships between PICES and other groups to advance the science of thresholds and leading indicators of ecosystem change

We encourage participation by other PICES, ICES, and IndiSeas members, as well as colleagues outside of these communities, who have expert knowledge of the ecological and human dimensions of North Pacific marine ecosystems and who have experience developing and implementing frameworks to quantify nonlinearities and thresholds in driver-response relationships

# **Abstracts**

## PLENARY SESSION ABSTRACTS

**June 5, 9:05/Plenary-S13-13087**

### **Interactions of global change with nutrient limitation of marine primary producers: How do we get from experimental bottles to whole ecosystem responses?**

David Allen **Hutchins**

University of Southern California, Marine and Environmental Biology, Los Angeles, CA, USA. E-mail: dahutch@usc.edu

A long-standing paradigm in biological oceanography is Liebig's Law of the Minimum, whereby whichever nutrient is in shortest supply proximately limits the growth of marine phytoplankton. However, it is now widely recognized that simultaneous limitation by multiple resources (co-limitation) is common in marine primary producers, and also that numerous other environmental factors can have complex, non-linear interactions with such nutrient (co)limitations. Further complicating the picture, both nutrient limitations and many of their associated and interacting factors such as temperature, carbonate chemistry, oxygen, and light are currently in flux in a rapidly changing ocean environment. It is extremely challenging to experimentally address these types of dynamic relationships between a diverse suite of many simultaneously shifting controls on marine phytoplankton. I will present examples from our experimental work that illustrate the types of unforeseen outcomes that can occur when ocean acidification or sea surface warming interacts with iron and nutrient limitation and co-limitation of marine diatoms and nitrogen-fixing cyanobacteria. Carefully designed multi-variable experimental approaches can be used to support more realistic global biological and biogeochemical models of changing marine ecosystems, and perhaps ultimately help to predict the resources that will be available to us from the altered food webs of the future ocean.

**June 5, 9:35/Plenary-S12-13103**

### **Getting the big picture in focus: Assessing climate and human factors with global human-ecosystem models**

Eric D. **Galbraith**<sup>1,2</sup>, Kim Scherrer<sup>1</sup> and Jérôme Guet<sup>1</sup>

<sup>1</sup> Universitat Autònoma de Barcelona, Bellaterra, Spain. E-mail: eric.galbraith@uab.cat

<sup>2</sup> ICREA, Barcelona, Spain

Climate change is impacting many aspects of marine ecosystems, with implications for fisheries and global food security. These impacts are occurring alongside rapid transformations in global societies and economies, and a human population that is expected to reach 10 billion this century. The large number of moving pieces makes it difficult to understand interactions between them, and to assess which elements are most important at the global scale. Global coupled human-ocean models offer a means by which to quantitatively gauge multiple climate and non-climate factors, and to conduct future scenario-based projections to estimate the outcomes of different societal choices. The current generation of global fishery models generally predicts an overall decrease of fish harvest as a result of warming. The rate of decline differs between models, but a major unifying factor appears to be the temperature-sensitivity of metabolism among ectotherms. However, historical model 'hindcasts' of the global fishery suggest that increasing technical proficiency of the global fishing fleet has been the main driver of historical change, and suggest that future technological progress could exceed the importance of climate change in the future, in the absence of effective regulation. These results imply that the regulation of fishing effort will be significantly more important for global harvest in the future than it has been in the past. Our results suggest that improved fishery regulations may be able to compensate for the 21<sup>st</sup> century impact of climate change on total global harvest, dependent on the ability of societies to enforce them.

**June 5, 10:05/Plenary-S3-12828**

## **Sentinel studies of ocean acidification in pelagic (the western North Pacific and Arctic Ocean) and Japanese coasts**

Naomi **Harada**<sup>1</sup>, Katsunori Kimoto<sup>1</sup>, Jun Kita<sup>2</sup>, Jonaotaro Onodera<sup>1</sup>, Masahiko Fujii<sup>3</sup>, Masahide Wakita<sup>1</sup>, Tetsuichi Fujiki<sup>1</sup>, Shintaro Takao<sup>4</sup> and Tsuneo Ono<sup>5</sup>

<sup>1</sup> Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan. E-mail: haradan@jamstec.go.jp

<sup>2</sup> Marine Ecology Research Institute, Kashiwazaki, Japan

<sup>3</sup> Hokkaido University, Sapporo, Japan

<sup>4</sup> National Institute of Polar Research, Tachikawa, Japan

<sup>5</sup> Japan Fisheries Research and Education Agency, Yokohama, Japan

Ocean acidification (OA) has become environmental stressor not only in pelagic ocean but also along coasts. According to Wakita *et al.*, (2017, JGR Oceans 122, doi:10.1002/2017JC013002), annual mean  $\text{pH}^{\text{in situ}}_{\text{T}}$  at St. K2 (47°N, 160°E) in the western North Pacific reduced significantly during 1999-2015 at a rate of 0.0025 year<sup>-1</sup>. The reduction rate of  $\text{pH}^{\text{in situ}}_{\text{T}}$  at St. K2 also indicated the seasonal change, namely slow down (0.0008 year<sup>-1</sup>) during the winter season than that of annual mean rate. This would relate with a reduced rate of increases of dissolved inorganic carbon, and an increase of total alkalinity in winter associated with the weakening of calcification by marine calcifier. In addition to pH, saturation degree is also important index for organisms and undersaturation area for aragonite has recently expanded in the Canada Basin as consequences of the accelerated sea ice melting (Yamamoto-Kawai *et al.*, 2009, Science 326, doi:10.1126/science.1174190). On the other hand, in terms of coastal area, Japanese coast and its surrounding area in the western North Pacific has faced to serious state for OA and pCO<sub>2</sub> and pH has monitored with temperature and salinity at Oshoro (Hokkaido), Akkeshi (Hokkaido), Mutsu (Aomori), Miyako (Iwate), Kashiwazaki (Niigata), Tateyama and Onjuku (Chiba), Shimoda (Shizuoka), and Sesoko (Okinawa). The dynamic diurnal and seasonal fluctuation of pH, saturation degree of carbonate and pCO<sub>2</sub> values is characteristic at coastal locations. According to incubation experiment of abalone, low saturation degree of aragonite and high pCO<sub>2</sub> under/upper threshold level gave a negative impact on an individual especially larvae (Onitsuka *et al.*, 2018, Mar. Env. Res., in press). Thus, appearance of lower threshold level of saturation degree of carbonate within the large diurnal amplitude might be key phenomenon weather marine calcifier's survival succeed or not at coastal area. In this presentation, the latest activities on pelagic and coastal OA studies promoted in Japan will be introduced including development of new technique to quantify the marine calcifier's response on OA.

**June 6, 8:50/Plenary-S14-13265**

## **Community vulnerability assessments to inform coastal adaptation planning: Insights from Southern Africa**

Merle **Sowman**

Department of Environmental and Geographical Science, University of Cape Town, South Africa. E-mail: merle.sowman@uct.ac.za

Coastal communities who depend on marine ecosystems and resources for food and livelihoods are particularly at risk from the impacts and uncertainties associated with climate change. Enhancing understanding of the vulnerability of these complex socio-ecological systems to climate variability and change is necessary to develop locally appropriate adaptation strategies and plans. While significant research has been undertaken to develop and apply methodologies to assess vulnerability across a range of contexts, identify climate-related impacts as well as mitigation measures and adaptation strategies, the practical implementation of locally appropriate adaptation actions remains a challenge. This paper reports on a community level vulnerability assessment methodology developed and applied in coastal fishing communities in Angola, Namibia and South Africa within the Benguela Current Large Marine Ecosystem region. It outlines the processes employed to develop and apply the methodology, as well as the logic of the steps involved to gain an understanding of local values, perceptions and knowledge regarding climate-related issues and impacts, perceived and observed changes, and existing and potential adaptation responses. Selected findings and outcomes from these vulnerability assessments are presented including how local knowledge on changing environmental conditions resonates with available science and how this presents opportunities for transformative learning. Coastal communities identified a number of adaptation strategies that could address vulnerabilities and enhance resilience but require support from a range of governance actors. Furthermore, moving beyond the identification of adaptation strategies to implementation action requires ongoing engagement of community participants in adaptation planning and implementation processes. The

presence of local champions, support from an external organisation/partner, access to some financial resources and a policy environment and institutional culture that recognises the value of community involvement in adaptation planning are all important requirements for the transition from adaptation ideas to adaptation actions. Participation of affected communities in these processes enhances understanding, builds capacity, opens up new spaces for engagement between local communities, scientists and other governance actors and generates knowledge for adaptation and management. Integrating knowledge from these community level processes both vertically and horizontally will lead to adaptation planning and implementation that is more integrated, locally appropriate and sustainable.

**June 6, 9:20/Plenary-S15-12764**

### **Vulnerable yet viable: Fisheries and aquaculture amidst global change processes**

Prateep Kumar [Nayak](#)

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This talk will focus on a fundamental question pertaining to the sustainability of marine and inland water ecosystems: what strategies and approaches can be used to build on the existing strengths to reduce vulnerabilities and enhance viability of fisheries and aquaculture systems in the face of persistent global change, including climate change. I will examine possible approaches and tools to augment existing strengths that will help build strategies to respond to global change related challenges facing fisheries and aquaculture sector. Social wellbeing, resilience, access to capitals, and human rights will be discussed as holistic and integrated approaches that can trigger viability. I then turn to a number of global instruments, 1) Voluntary Guidelines for securing sustainable small-scale fisheries, 2) Sustainable Development Goal 14 (Life below Water), 3) FAO Code of Conduct for Responsible Fisheries and 4) FAO Ecosystem-based approaches to Fisheries and Aquaculture and coastal management, to discuss best practices that can empower fisheries and aquaculture communities to assess their vulnerabilities, realise their strengths, and develop adaptive capacity and resilience. Adoption of best practices can and will enable critical coastal ecosystems to adapt to the effects of climate change, and to reduce the threats from other environmental stresses. Managers need to adopt and adhere to these best practices to help build resilience to the effects of climate change. Overcoming vulnerabilities and bringing into play existing and newly acquired strengths will lead to the viability of fishery and aquaculture systems with positive implications for sustainable coastal livelihoods and food security.

**June 6, 9:50/Plenary-S10-13238**

### **Addressing key questions for climate-driven species redistribution requires integration of ecology, conservation and social science**

Gretta [Pecl](#)<sup>1, 2</sup>

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Climate change is driving a pervasive global redistribution of the planet's species, with manifest implications from genes to ecosystems across multiple temporal and spatial scales. Species redistribution defies conservation paradigms that focus on restoring systems to a baseline and challenges management strategies, which are often static and based on human-dictated boundaries drawn in the past. Likewise, changes in distribution of marine resources create difficulties, particularly when species cross jurisdictional boundaries and where historical catch rates and assessment processes may no longer be appropriate. Moreover, we are still a long way from understanding the suite of mechanisms and processes underlying the high variation in rate and magnitude of shifts. Building on that uncertainty, we have even less understanding of how species redistribution will drive changes in ecological communities and further complicate aspirations of ecosystem-based management. Climate-driven species redistribution therefore presents intriguing ecological challenges to unravel, as well as fundamental philosophical questions and urgent issues related to conservation, food security, Indigenous and local livelihoods, and many other aspects of human well-being. This presentation will highlight some of the key questions for climate-driven species redistribution in marine systems in the context of ecology, conservation, natural resource management and social science. Understanding range shifts from ecological, physiological, genetic and biogeographical

perspectives is essential for informing and designing conservation and natural resource management strategies for a changing future. However, for species redistribution research to support development of relevant adaptive strategies and policy decisions adequately, studies need to take an interdisciplinary approach and must recognise and value stakeholders.

**June 6, 10:20/Plenary-S4-13214**

### **Climate variability and ocean deoxygenation over continental margins associated to the Peru-Chile and other upwelling systems: Insights from proxy records**

Dimitri Gutierrez<sup>1, 2</sup>

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Ocean models are still limited to reproduce or predict current and future trends of the dissolved oxygen content along most of the continental margins that are intersected by large oxygen minimum zones (OMZs), which also feature or are influenced by intense coastal upwelling systems. A comparison of paleorecords of the Peru/Chile margin with those from other analog systems mainly during the last millenium, may help to gain insights on the sensitivity of water column oxygenation (WCO) to climate-driven forcings in these regions at multidecadal or longer time-scales. Temporal and spatial variations of the proxy records suggest that the Walker circulation is the principal factor that modulate the OMZ intensity and the upwelling productivity off Peru and Northern Chile; while the formation rate of the oxygen-rich Eastern South Pacific Intermediate Waters, associated to meridional shifts of the subtropical front, exerts an influence on the subsurface ventilation at higher latitudes. WCO over the California margin also appears to be modulated by the equatorial remote forcing, through changes of the oxycline depth, surface productivity and the advection of oxygen-poor water by the California undercurrent. On the other hand, proxy records from the Namibian shelf and from the Arabian Sea indicate a coupling of WCO with surface productivity driven by coastal upwelling or monsoon upwelling intensity, respectively, which in turn are influenced by meridional displacements of the ITCZ. Noteworthy, while negative trends of oxygenation proxies are detected for the last decades in the California margin and Namibian shelf, at the Peru-Chile margin, no trends or weak positive trends can be estimated in the same period. Differential responses among these systems should be considered and better understood to disentangle global, remote and regional forcings for future ocean deoxygenation under climate change.

**June 7, 8:50/Plenary-S7-12997**

### **Sensitivity of the Eastern Tropical South Pacific oxygen minimum zone to climate change**

Andreas Oschlies

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Observations reveal a substantial expansion of low-oxygen waters in the tropical oceans including the ETSP during the past decades. Current numerical models underestimate the observed rate of deoxygenation, and global models tend to show particularly large misfits for ETSP oxygen changes. The presentation will investigate possible mechanisms that can explain these misfits and quantitatively analyse these with global and regional models. In particular, the roles of local and remote wind versus temperature forcings are investigated, as are biogeochemical feedback mechanisms, such as redox-sensitive benthic-pelagic exchange of phosphorus and iron, and the linkage between nitrogen loss processes and nitrogen fixation. The presentation will end with a discussion of emerging constraints on likely future changes in the ETSP under continued global warming.

**June 7, 9:20/Plenary-S17-13258**

### **Climate change, harmful algal blooms and health risks in one health context**

Iddya **Karunasagar** and Indrani Karunasagar

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Climate change and the accompanying alterations in the ocean ecosystem have been impacting seafood industry and risks associated with seafood consumption. Ciguatera fish poisoning has been related with the consumption of fish and other marine products, mainly from tropical coral reef areas containing toxin produced mainly by the marine dinoflagellate algae belonging to *Gambierdiscus* spp. There is increasing evidence to indicate that the geographical range of ciguatera has been expanding. In 2016, there was an outbreak of ciguatera fish poisoning involving over 100 people in Mangalore, South West Coast of India. Outbreaks related to fish from Canary islands (Eastern Atlantic ocean) and Greece (Mediterranean waters) further support the hypothesis that climate change is causing increased risks associated with seafood. Increasing temperature may modify water circulation patterns and cells physiology, with an overall impact on harmful algal blooms occurrence. Climate change may alter frequency and intensity of upwelling, which will influence harmful algal blooms.

There is already convincing evidence to show that bacterial pathogens like *Vibrio parahaemolyticus* can spread through phytoplankton in warm oceanic currents associated with El Nino events. Though clinical cases related to molluscan shellfish associated pathogen *Vibrio vulnificus* have been reported from few countries, the geographical distribution is wider than it has been thought. The emerging scenario of increase in elderly population due to extension of life expectancy and creation of oceanic conditions suitable for *Vibrio* populations warrant considering these pathogens in seafood safety risk assessments. Detection of low levels of tetrodotoxin in bivalves and the association between *Vibrio* spp and tetrodotoxin, has led to the thinking that considerations need to be given on the changing scenario of seafood associated health risks.

**June 7, 9:50/Plenary-S2-13257**

### **Ten-years out: Navigating the information gap between El Niño and climate change**

Lisa **Goddard**

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The climate varies on all timescales: from months to decades to centuries. Climate change research typically focuses on anticipated end-of-century climate changes due to increased greenhouse gasses in our atmosphere. For climate adaptation, however, the time horizons to plan, implement, and evaluate adaptation measures are typically less than 20 years in the future. At these shorter time horizons, natural decadal variability can confound anthropogenic climate change. Natural decadal variability can be driven by large-scale oceanic processes, and thus potentially predictable, or decadal variability can be purely stochastic. I will discuss what we know about decadal climate variability: that important intersection between variability and change. I will describe what we know about the oceanic drivers of decadal variability, provide some examples of regional impacts – on land and sea, and outline some of the research to apply decadal-scale climate information.



**June 7, 10:20/Plenary-S11-12803**

**How do we put all the pieces together to appreciate the bigger picture?**

Steve Widdicombe

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The overall response of marine ecosystems to a rapidly changing ocean is governed by a complex matrix of physiological responses and ecological interactions, both within and between individual organisms. Stress induced changes in individuals' performance will affect population success, largely through altering competitive, facilitative and trophic relationships, ultimately driving shifts in ecosystem structure and functioning. Predicting long-term ecosystem level effects of climate change is therefore challenging and largely reliant on generating understanding across all levels of biological organization. In many previous studies which have sought to describe the impacts of climate change, it has been impossible to fully mimic the spatial or temporal scales, or indeed the levels of complexity and variability, over which climate change will operate. Whilst methods for studying each of the separate organizational levels over specific temporal and spatial scales are well developed, *e.g.* manipulative experiments and observations in the field and in the laboratory, the tools needed to integrate understanding from these separate studies are less well advanced. Further developing these integrative tools will support a more comprehensive appreciation of the future fate of marine organisms, populations and, ultimately, whole marine ecosystems. This talk will explore some examples in which data and knowledge have been successfully scaled up to make predictions at higher, more complex, levels of ecological organization.

**June 8, 8:50/Plenary-S18-13250**

**Blue carbon ecosystems: Conservation and policy needs for an effective climate change adaptation and mitigation strategies**

Severino G. Salmo III

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Blue carbon ecosystems (mainly mangroves, seagrass and tidal marsh) sequester atmospheric CO<sub>2</sub> and store it in the sediments as carbon for long period (for at least 100 yrs). These processes of sequestration, deposition and storage significantly contributes in reducing CO<sub>2</sub> thereby provide viable adaptation and mitigation strategies in reducing the impacts of climate change. But, the performance of carbon sequestration of these ecosystems is strongly dependent on their extent and ecosystem health. These ecosystems are regularly subject to various forms of both natural and anthropogenic disturbances particularly in developing countries. The loss of these ecosystems will result to the release and return of long-stored carbon as greenhouse gas (GHG) in the atmosphere. In the Asia-Pacific region, while massive restoration programs were implemented since 1990s, these ecosystems still experience perturbations. Moreover, the limited monitoring data (on spatio-temporal status and carbon stock values) combined with lack of appreciation on their ecological importance will further contribute in their mismanagement. Citizen science can be a potent tool in at the least providing managers and policy makers information that will be needed in the appreciation of carbon sequestration, as well as in the implementation of financial carbon trading scheme. This information will then serve as technical inputs in the formulation of Blue Carbon monitoring and management plan in at least at national scale and scaled up at international level.

**June 8, 9:20/Plenary-S1-12572**

### **Ocean Extremes: Marine Heatwaves and Marine Ecosystems**

Alistair **Hobday**<sup>1</sup>, Neil Holbrook<sup>2</sup>, Eric Oliver<sup>3</sup>, Dan Smale<sup>4</sup> and Thomas Wernberg<sup>5</sup>

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Considerable attention has been directed at understanding the consequences and impacts of long-term anthropogenic climate change. Discrete, climatically extreme events such as cyclones, floods, and heatwaves can also cause considerable impacts on regional environments, species, and humans – and both interannual variability and anthropogenic climate change is expected to exacerbate these effects. Climatic extremes also occur in the ocean, and recent decades have seen many high-impact marine heatwaves (MHWs) – anomalously warm water events that may last many months and extend over thousands of square kilometres. I will describe a range of biological, economic and political impacts that have been associated with some intense MHWs, historical and projected trends in these events, and the role of attribution for communication and mechanistic understanding. While extremes impact on a range of marine users, adaptation is also possible with a risk-based predict-and-prepare strategy. Improved short-term and seasonal forecasting tools are an important element in the “predict” strategy. My work with a range of stakeholders has also helped me to develop the “prepare” part of a climate-proofing strategy. Growing public interest in marine extreme events means that measuring the severity of these phenomena in real time is becoming more important, and I propose a method for consistent description of MHWs that is compatible with an underlying long term trend.

**June 8, 9:50/Plenary-S8-13256**

### **Facing the future and sustainability through connecting the coastal and open oceans: Center for Ocean Mega-Science, Chinese Academy of Sciences**

Fan **Wang**

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Contemporary marine sciences are multi-disciplinary, ambitious, heavily funded, and possess large-scale facilities, clear indicators of Mega-Science. An overview of the world’s major powers in marine science and technology suggests that these countries share clear national objectives and celebrate the intersection and integration of various disciplines, thus forming comprehensive marine research facilities that adapt to the requirements of research in Mega-Science. The Chinese Academy of Sciences (CAS) is establishing the Center for Ocean Mega-Science in the CAS Science and Education Park in Qingdao, relying heavily on the Institute of Oceanology and also on other 12 CAS institutes majoring in earth science, life science, and high technology development fields. The center will integrate and coordinate the CAS research vessels, fundamental instruments, field observing networks, and big data center as its main supporting facilities. The center aims to constitute an innovative platform of science and technology in marine sciences that enables open and efficient sharing, offers an advantageous training site for elite personnel, and serves as a research center with international influence, facilitating collaborative innovations domestically and abroad. The center is poised to face the issues relevant to the future sustainability of the sea, by integrally promoting the “healthy ocean” demonstration in the coastal sea, study of multi-spherical interactions in the Indo-Pacific convergence zone, and green utilization of biological resources. The center is committed to enhancing awareness and understanding of regional and global marine issues, and developing innovative solutions that will serve as important technological support for the implementation of domestic and international ocean sustainability strategies.

## ORAL PRESENTATIONS

### S1: Ocean extremes and their impact on marine ecosystems

June 5, 11:00/S1-Invited-13137

#### Trophic mismatches between plankton blooms and fish spawning phenology as a function of climate extremes

Rebecca G. [Asch](#)<sup>1</sup>, Charles Stock<sup>2</sup> and Jorge Sarmiento<sup>3</sup>

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<sup>3</sup> Princeton University, Princeton, NJ, USA

Commercially important fishes experience recruitment variability of 2-3 orders of magnitude, which is influenced by spatial and temporal synchrony in the distribution of larval fishes and their planktonic prey. Under climate change, seasonal synchrony between organisms is hypothesized to decrease, reflecting the fact that stratification and mixing affect plankton bloom phenology whereas temperature exerts a strong influence on fish spawning phenology. Using an earth system model, we explore whether increases in temperature extremes may lead to a greater frequency of trophic mismatches among fishes with two spawning behavior modes. We analyze changes in mean phenological mismatches and “extreme mismatches” where fish spawning and bloom initiation are separated by >30 days. Extreme mismatches have a greater likelihood of resulting in recruitment failure due to their prolonged duration relative to the length of fish egg and yolk-sac larvae stages. For fishes that exhibit spawning site fidelity in the North Pacific, we project a 10-fold increase in the area experiencing extreme mismatches throughout the 21<sup>st</sup> century, with a 3-fold increase in the North Atlantic. For fishes that undergo range shifts in spawning locations, there is greater spatial variability, with the frequency of extreme mismatches increasing in some areas but decreasing in others. Extreme mismatches increased more rapidly than projected changes in mean matches/mismatches between trophic levels. Empirically observed mismatches of the same magnitude as those in our model have altered planktonic species composition and distribution, reduced and delayed recruitment, led to reproductive failure among seabirds, decreased fishery profitability, and contributed to fishery collapse.

June 5, 11:30/S1-Oral-12649

#### Inland sea and coastal ocean zooplankton communities show contrasting responses to recent Northeast Pacific climate variability

Julie E. [Keister](#)<sup>1</sup>, Jan Newton<sup>1</sup>, Jennifer Fisher<sup>2</sup>, Ian Perry<sup>3</sup>, William T. Peterson<sup>2</sup>, Moira Galbraith<sup>3</sup>, John Mickett<sup>1</sup>, Bethellee Herrmann<sup>1</sup> and Wendi Ruef<sup>1</sup>

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<sup>2</sup> Hatfield Marine Science Center, Newport, OR, USA

<sup>3</sup> Fisheries and Oceans Canada, Nanaimo, B.C., Canada

Diagnosing the mechanisms that connect environmental change to food webs is important to managing and forecasting ecosystems. Extreme events provide strong contrasts to typical conditions, enabling clearer links from the physics to ecosystems to be drawn. Similarly, examining differences among locations with contrasting responses to change can help understand the underlying ecosystem drivers. Over the past several years, the Northeast Pacific has experienced a broad range of conditions from average to unprecedented anomalies. We use zooplankton monitoring data from the coastal Pacific Northwest and inland regions of the Salish Sea to explore spatial and interannual variability in zooplankton community response to environmental change over the period of 2014-2017. Large shifts in the physical environment had strong effects on zooplankton community structure and abundance in all locations. 2014 began as a fairly normal year until the Pacific Warm Anomaly event nicknamed “The Blob” began to affect the region during late summer and fall. Unprecedented warm conditions occurred in summer 2015, persisting through 2016. In the coastal ocean, clear effects on zooplankton community structure have been reported, with rare oceanic copepod species and high species diversity occurring in coastal samples, concurrent with decreased overall biomass. In sharp contrast, few rare species were collected in the inland seas, and the opposite trend in zooplankton biomass occurred, with increases in many of the dominant taxa during the warm anomalies relative to 2014. These and other contrasts observed in zooplankton response among systems are explored to understand the physio-chemical underpinnings of the observed changes and their implications for local and regional effects on fish populations.

**June 5, 11:50/S1-Oral-13131**

**Time to expect the unexpected? Unprecedented warming and a chain of ecosystem impacts link altered forage fish distribution and crab fishery delays to a spike in whale entanglements along California's central coast in 2015-2016**

Jarrold A. Santora<sup>1,2</sup> and Nathan Mantua<sup>2</sup>

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Extreme climate events are expected to disrupt marine ecosystem structure and function, potentially leading to unexpected nonlinearities in trophodynamics of food webs that impact ecosystem services. The recent Large Marine Heatwave (LMH) in the Northeast Pacific was unprecedented, with record single-year sea surface temperature (SST) anomalies in the California Current Large Marine Ecosystem (CCLME). Here, we document key elements of the chain of ecosystem and fishery impacts that resulted in a record number of whale entanglements in crab fishery gear along California's central coast in 2015 and 2016. Using a combination of remote-sensing and fishery surveys, we argue that key ingredients in the LMH-related ecosystem impacts included: 1) shifts in the abundance, distribution and biodiversity of pelagic forage species (*e.g.*, krill and anchovy); 2) a record harmful algal bloom that caused widespread elevated Domoic Acid (DA) concentrations within the shelf waters of the CCLME; 3) DA contaminated Dungeness crab (*Cancer magister*) along the U.S. West Coast; and 4) an onshore shift of foraging whales. A key human-dimension to the whale entanglements was the unprecedented 5-month delay in the opening of the California Dungeness crab fishery because of the persistent DA contamination. We also review how these unexpected outcomes of the LMH were translated to a recently formed working group composed of fishery stakeholders, resource managers and conservationists. We present this case-study as a potential model for the kind of ecosystem and fishery interactions that are likely to become more frequent as global change moves us into a no analog future.

**June 5, 12:10/S1-Oral-12775**

**Effects of a recent marine heat wave on forage taxa in the northern California Current: An unprecedented ecosystem shift in progress?**

Richard Brodeur<sup>1</sup>, Mary Hunsicker<sup>1</sup>, Toby D. Auth<sup>2</sup> and Todd W. Miller<sup>3</sup>

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<sup>3</sup> NOAA, Alaska Fisheries Science Center, Auke Bay, AK 99821, USA

Forage taxa play a central role in the transfer of energy from lower to higher trophic levels. Ocean conditions may influence this energy pathway in the northern California Current (NCC) ecosystem. The recent unprecedented prolonged warming in the NCC provides a unique opportunity to better understand the connection between ocean conditions and forage taxa abundance and distribution patterns and feeding. We present findings from two studies that suggest that the recent warming period associated with the 'Warm Blob' and El Niño affected forage significantly. Pelagic trawl surveys were conducted off Oregon and Washington during early summer of 2011 and 2013-2016 and examined for interannual changes in spatial distribution of fish and invertebrate taxa. The community was significantly different in both 2015 and 2016 than the earlier cool years. Crustacean plankton densities were extremely low in both years, and the invertebrate composition became dominated by gelatinous zooplankton. Stomach collections of multiple forage fishes off the Washington and Oregon coasts were examined from June during recent warm years (2015 and 2016) and compared to previous collections from 2000, 2002, 2011, and 2012 (average or cool years). Fish feeding habits varied significantly between cold and both average and warm periods. Euphausiids, decapods, and copepods were the main prey items of the forage fishes in cool years; however, gelatinous zooplankton were consumed in higher quantities in warm years. The substantial reorganization of the pelagic forage community has the potential to lead to major alterations in trophic functioning in this normally productive ecosystem.

**June 5, 12:30/S1-Oral-13132**

## **Understanding how extreme conditions and ocean acidification uniquely influence coastal upwelling zones: A case study from the Pacific Northwest U.S.**

Jan **Newton**<sup>1</sup>, John Mickett<sup>1</sup>, Simone Alin<sup>2</sup>, Adrienne Sutton<sup>2</sup> and Richard Feely<sup>2</sup>

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Coastal oceans are some of the most productive and economically important ocean regions, yet more knowledge of ocean status comes from open-ocean measurements. Coastal records, often relatively short, are advancing as more nations sustain ocean observing systems. The Cha'ba buoy off Washington, USA, sustained since 2010 by US-IOOS/NANOOS, reveals patterns with relevance to ocean extremes and their impact on marine ecosystems. Most notable was the effect of the 2014-2016 North Pacific marine heat wave, which caused large temperature anomalies in coastal waters, primarily during fall when conditions shifted from upwelling to downwelling. Even at depth (85 m), a ~4°C temperature anomaly rapidly followed a shift in wind direction. Associated rapid changes in salinity, oxygen, and pH also occurred. The upshot is that coastal species can experience very abrupt changes in conditions associated with marine heat waves in locales where upwelling/downwelling dynamics dominate. The record of atmospheric and seawater pCO<sub>2</sub> at this buoy and a NOAA buoy at Cape Elizabeth (2006-present) shows a year-to-year increase in atmospheric pCO<sub>2</sub> with time, yet more variable seawater pCO<sub>2</sub> dynamics and no temporal trend evident. This is likely due to the many local variables that can affect seawater pCO<sub>2</sub>, including temperature, primary production, and upwelling/downwelling, all of which are influenced by climate variables, e.g., sunlight, winds, and air temperature. Not all of these factors cause changes in pCO<sub>2</sub> in the same direction, thus yielding a pattern predicted to be variable. Thus, extreme climate/ocean conditions may result in highly unpredictable coastal ocean conditions with large ranges.

**June 5, 12:50/S1-Oral-13099**

## **How “The Blob” affected groundfish distributions in the Gulf of Alaska**

Qiong Yang<sup>1</sup>, Edward Cokelet<sup>2</sup>, Phyllis Stabeno<sup>2</sup>, Lingbo Li<sup>3</sup>, Anne **Hollowed**<sup>3</sup>, Wayne Palsson<sup>3</sup>, Nicholas Bond<sup>1</sup> and Steven Barbeaux<sup>3</sup>

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<sup>3</sup> Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA, USA

We investigated changes in the distributional shifts of groundfish in the Gulf of Alaska (GOA) in response to the anomalous warm ocean conditions during the recent “blob” event (2015). A 10-year dataset of fish abundance, bottom temperature and depth from Alaska Fisheries Science Center bottom trawl surveys during the period of 1996–2015 was analyzed. Among the 10 survey years, 2015 was the warmest year. Six fish species including Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (*Atheresthes stomias*), Pacific ocean perch (*Sebastes alutus*), walleye pollock (*Gadus chalcogrammus*), northern rock sole (*Lepidopsetta polyxystra*) and southern rock sole (*Lepidopsetta bilineata*), were considered. Fish were binned by size to account for ontogenetic differences. We applied a joint probability density distribution (PDF) of bottom temperature and depth to represent the distribution of fish abundance. The changes in fish centroid depth were related to the changes in habitat temperature. Our results suggest that groundfish exhibit complex distributional responses to changes in ocean temperatures. No noticeable distributional shifts were found for walleye pollock and southern rock sole. Young fish were less responsive to changes in ocean temperature while older fish were more responsive. Pacific cod and arrowtooth flounder tended to move deeper in warm waters and shallower in cold waters.

**June 5, 14:20/S1-Oral-13164**

### **Marine ecosystems and extreme events: A global analysis through the lens of seabirds**

William J. Sydeman, Sarah Ann Thompson and the Seabird-Climate Working Group

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As the world warms, extreme marine climate events are becoming more frequent and intense, but the consequences of these events on marine ecosystems are poorly understood. Well-known and monitored ecological indicators are needed to assess changes across ecosystems at the global scale. Seabird productivity is such an indicator. Marine climate mostly affects seabird breeding success indirectly through bottom-up mechanisms of changing ocean conditions on the availability of mid trophic level forage (fish and zooplankton). Forage availability is affected by natural ecosystem processes and climate variability, as well as fisheries management. In this study, we test the hypothesis that ecosystem functions have become more variable through time by examining systematic change in the variance structure of seabird productivity (*i.e.*, breeding success female<sup>-1</sup>). To test this hypothesis, we compiled a global dataset of standard measurements of seabird productivity and analyzed changes in variance at the interannual scale relative to ecosystem-scale changes in climatic and anthropogenic (fisheries prey depletion) factors. Data for this analysis comes from tropical, temperate, and sub-polar ecosystems. In particular, we assessed if increasing variability in seabird productivity is associated with recent marine heat waves (MHW) across the globe. On the global scale, seabird breeding success has become more variable, especially in the past decade, but attribution to climate change and MHW is complicated by the fact that few ecosystems remain unaffected by fisheries. Nonetheless, we suggest that focus on under-appreciated variance statistics may reveal unanticipated effects of climate change on the world's oceans and marine life.

**June 5, 14:40/S1-Oral-13216**

### **Extreme response of seabirds to extreme climate events in the NE Pacific**

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The astonishing abundance and diversity of seabirds in the North Pacific is evidence in itself that seabirds are highly successful at exploiting forage fish populations in a dynamic and often hostile marine environment. Despite their remarkable abilities, however, seabirds occasionally exhibit extreme responses to short-term food scarcity in the form of mass mortality events (“wrecks”) or complete reproductive failures at colonies. These rapid and extreme responses likely occur in seabirds because their daily energy demands are also extreme (especially in comparison to other marine piscivores such as groundfish, pinnipeds and whales). The response of seabirds to climate change at differing temporal scales can best be framed by decomposing long-term ocean temperature variability into the modes of change that contribute most to the thermal environment. In the NE Pacific, modes of variation that have a strong impact on seabirds and forage fish include predictable climate variability associated with (in order of contribution): 1) seasonal changes in insolation, 2) global warming, 3) the Pacific Decadal Oscillation, 4) El Niño, and, 5) as-yet unexplained or random variability that can also have a major impact on seabirds, especially when it produces extreme thermal anomalies over large areas (*e.g.*, the “Blob”). Finally, impacts can be most pronounced when modal signals are synchronized, as they were during the 2014-2016 marine heat wave when 100,000s of Common Murres in the California Current and Gulf of Alaska marine ecosystems perished from starvation.

**June 5, 15:00/S1-Oral-12771**

### **Robustness of food web complex networks to heat-waves in tropical and temperate shallow waters**

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While there is evidence that tropical organisms are more vulnerable to climate warming than their temperate counterparts, little is known about the differential response of tropical and temperate food webs to increasing temperatures and extreme thermal events. Understanding the effects of climate warming on complex food webs over large ecosystems presents high costs and oftentimes unsurmountable logistical challenges. This way, it is crucial to find smaller systems that can be used as proxy food webs. Intertidal rock pool environments harbor particularly high biodiversity over small areas and are particularly vulnerable to warming due to their small volume. This study aimed to analyze their food web networks' response to sequential species removals and compare the robustness of tropical and temperate webs. Highly resolved food webs were assembled for 34 intertidal rock pools from a tropical and a temperate region. Upper thermal limits were experimentally determined for the most common rock pool organisms in both areas, allowing the assemblage of rankings of thermal vulnerability. Species were sequentially removed from the food webs according to their thermal vulnerability. The structural 'robustness' of each food web to species loss was calculated as the fraction of species that had to be removed in order to result in total species loss (i.e. primary species removals plus secondary extinctions) of  $\geq 50\%$  of the species in the original web. It was revealed that although the robustness of tropical and temperate food webs was similar, the tropical webs experienced significant alterations in more network properties.

**June 5, 15:20/S1-Oral-12585**

### **Warmer doesn't mean weaker: Impact of heatwaves on foundation macrophyte species**

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Marine heatwaves (MHWs) have been observed throughout the world and are expected to increase both in frequency and intensity under climate change scenarios causing additional stress to organisms. Macrophytes like the temperate brown seaweed *Fucus vesiculosus* and the seagrass *Zostera marina* are widespread in the northern hemisphere providing core ecological and biogeochemical services. Thus, understanding the response of such foundation species to extreme events will improve our predictions of the responses of coastal marine ecosystems under climate change. Healthy functioning of macrophytes is intimately linked to the maintenance of growth, photosynthetic efficiency, resistance against pathogens, epibionts and consumers.

Thus, we tested the physiological and chemical defence responses of western Baltic Sea *Fucus* and *Zostera* population to simulated heatwaves in a novel outdoor mesocosm with a multidisciplinary approach. Along with control tanks, two different treatments were applied: treatment experiencing two spring heatwaves followed by a summer heat wave, a treatment experiencing just the summer heat wave. For both the macrophytes, physiological and chemical defence responses was not significantly affected among controls and two different treatments. Thus, we conclude that the well-being of *Fucus* and *Zostera* populations in the western Baltic Sea will hardly be weakened by such extreme heat bursts.

**June 5, 15:40/S1-Oral-13204**

### **Ecological impacts of the extreme 2015-2016 El Niño in the central equatorial Pacific**

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The central equatorial Pacific (CEP) fluctuates between anomalously warm and nutrient-poor El Niño and anomalously cool, nutrient-rich La Niña conditions. El Niño events are typically characterized by an eastward expansion of the Indo-Pacific warm pool (IPWP) and deepening of the thermocline and nutricline, with associated decreases in primary productivity in the eastern and central tropical Pacific and corresponding increases in productivity in the IPWP. Recent studies have shown that the IPWP has warmed and expanded in recent decades and that anomalously warm sea surface temperatures (SST) in the CEP during the extreme 2015-2016 El Niño were likely unprecedented and unlikely to have occurred naturally, and most probably influenced by anthropogenic greenhouse gas forcing. We further describe variations in SST, biological productivity, and ecological responses at both local island and regional scales to characterize the extreme 2015-2016 El Niño in relation to previous El Niño events in the CEP and in the context of climate trends. Unprecedented Chl-*a* anomalies and record high SSTs were observed in the CEP associated with warming trends in the IPWP during the extreme 2015-2016 El Niño. Catastrophic coral bleaching with 98% mortality, as well as noteworthy changes in reef fish and seabird communities, was observed at Jarvis Island. Changes to coral reef communities were modest at Howland, Baker, and Kanton Islands which experienced less severe thermal stress. Regionally, changes in catch rates from purse seine and longline fisheries were observed and will also be reported.

**June 5, 16:00/S1-Oral-13173**

### **Developing an index for early detection of abrupt change in northeast Pacific Ocean ecosystems**

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Ecological regime shifts are an important source of uncertainty, affecting our ability to successfully manage fisheries in the northeast Pacific (NEP). While past NEP regime shifts have been associated with sudden change in the Pacific Decadal Oscillation, an important prediction of ecological theory is that abrupt shifts are also expected in ecosystems undergoing persistent or incremental external perturbation. Though such shifts may be rare, the degree to which these events can disrupt marine resources can hardly be overstated. Thus, there is a need for novel approaches that can provide rapid detection of large-scale ecosystem shifts. Here we summarize information from a large set of biological time series from the California Current Ecosystem, Gulf of Alaska and Eastern Bering Sea to develop a State Index that can provide early detection of abrupt community-level changes in each ecosystem. We have developed and applied a Bayesian analog of Dynamic Factor Analysis (DFA), an ordination tool for time series, to regional data sets to evaluate changes in mean community state. In addition, we 1) tested for 'black swan' events in the shared DFA biological trends, 2) identified probabilities of shared trends being in a particular stable state, and 3) elucidated relationships between environmental conditions and the shared biological trends. Ultimately, the goal of our work is to develop reference points that enable scientists and managers to distinguish normal variability from changes signaling a major shift.



June 5, 16:40/S1-Oral-12645

### Marine heat waves under global warming

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Some of the recently observed marine heat waves (MHWs) demonstrated the high vulnerability of marine ecosystems to such extreme climate events. Yet, our knowledge about their past occurrences and their future progression is very limited. Here, using satellite observations and a suite of Earth system model simulations, we show that MHWs (defined as sea surface temperature (SST) conditions exceeding the preindustrial 99<sup>th</sup> percentile) have already become more frequent, extent, intense, and longer lasting in the last few decades and that this trend is bound to accelerate under further global warming. Over the satellite era, the probability of occurrence of a MHW went up by 130% and this probability will increase further 16-fold under 1.5°C and 23-fold under 2.0°C global mean warming relative to preindustrial levels. But currently, we are on the course towards a global mean warming of 3.5°C by the end of the 21<sup>st</sup> century, which would increase the probability of MHWs by a factor of 41. At this level of warming, MHWs have an average size that is 21 times bigger than in preindustrial times, last on average 112 days, and reach maximum intensities in SST of 2.5°C. The largest changes are projected to occur in the western tropical Pacific, the Arctic Ocean and in coastal waters. Already today, 87% (78-91%) of the MHWs are attributable to warming, with this ratio increasing to nearly 100% under any global warming exceeding 2°C. Our results suggest that MHWs are bound to become commonplace and very extreme under global warming.

June 5, 17:00/S1-Oral-12762

### Projected sea surface temperatures over the 21<sup>st</sup> century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans

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Global climate models were used to assess changes in the mean, variability and extreme sea surface temperatures (SSTs) in northern oceans with a focus on large marine ecosystems (LMEs) adjacent to North America, Europe, and the Arctic Ocean. Results were obtained from 26 models in the Community Model Intercomparison Project Phase 5 (CMIP5) and 30 simulations from the National Center for Atmospheric Research Large Ensemble Community Project (CESM-LENS). All simulations used observed greenhouse gas concentrations for 1976–2005 and the RCP8.5 scenario for greenhouse gases through the remainder of the 21<sup>st</sup> century. In general, differences between models are substantially larger than among the simulations in the CESM-LENS, indicating that SST changes are more strongly affected by model formulation than internal climate variability. SST changes over the 21<sup>st</sup> century are primarily due to a positive shift in the mean with only modest variability changes in most LMEs. The shift in the mean is so large that in many regions SSTs during 2070–2099 will *always* be warmer than the *warmest year* during 1976–2005. The SST trends are generally stronger in summer than in winter, as greenhouse gas heating is integrated over a much shallower climatological mixed layer depth in summer than in winter, amplifying the seasonal cycle of SST over the 21<sup>st</sup> century. In the Arctic, the mean SST and its variability increases substantially during summer, when it is ice free, but not during winter when a thin layer of ice reforms and SSTs remain near the freezing point.

**June 5, 17:20/S1-Oral-12732**

## **Increasing coupling between NPGO and PDO leads to prolonged marine heatwaves in the Northeast Pacific**

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The marine heatwave of 2014/2015 in the Northeast Pacific caused significant impacts on marine ecosystems and fisheries. While several studies suggest that land and marine heatwaves may intensify under climate change less is known about the prolonged multi-year nature (~2 years) of the Northeast Pacific events. Examination of reanalysis products and a 30-member climate model ensemble confirms that prolonged multi-year marine heatwaves are linked to the dynamics of the two dominant modes of winter sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). Specifically, we find a significant correlation between winter warm NPGO anomalies and the following winter PDO arising from extra-tropical/tropical teleconnections. In the model projections for 2100 under the RCP8.5 scenario, this NPGO/PDO 1 year lag-correlation exhibits a significant positive trend (~35%) that favors more prolonged multi-year warm events (>1°C) with larger spatial coverage (~18%) and higher maximum amplitude (~0.5°C for events >2°C) over the Northeast Pacific.

**June 5, 17:40/S1-Oral-12994**

## **Attribution of recent marine heat waves to anthropogenic climate change**

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Recent marine heat waves have caused increasing concern because of their devastating effects on marine ecosystems. Reported biological impacts range from geographical species shifts and widespread changes in species composition to harmful algal blooms, mass strandings of mammals and mass mortalities of particular species. In several cases, marine heat waves have led to the closing of commercially important fisheries and aquaculture industries.

Model studies indicate that marine heat waves are already more frequent, more intense, larger and longer lasting compared to pre-industrial times, and that these changes are amplified under future global warming. However, apart from the Tasmanian heat wave in 2015/16 it is not known to what extent anthropogenic climate change affected the likelihood of the occurrence and magnitude of recent prominent marine heat waves.

Here we use sea surface satellite and climate model data to quantify the human influence on the occurrence of individual recent marine heat waves. We first detect marine heat waves during the satellite era from 1982 to 2016 and rank them according to their intensity, duration and spatial extent. Preliminary results show that many of the largest and longest heat waves occurred in the tropical Pacific, possibly related to the El Niño-Southern Oscillation. We then select the largest and warmest heat waves and calculate the fraction of risk that can be attributed to anthropogenic climate change. To this end we compare the probabilities of extreme events in temperature projections of a suite of CMIP5 Earth System Models with and without anthropogenic forcing.

**June 5, 18:00/S1-Oral-12699**

### **Daily and seasonal ocean acidification extremes during the twenty-first century**

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How ocean acidification will affect marine organisms depends on changes in both the long-term mean and the short-term temporal variability of carbonate chemistry. While the decadal-to-centennial ocean acidification response to climate change is well constrained, little is known about corresponding changes in daily and seasonal extremes. Here such extremes are assessed by analysing 9 Earth System Models (ESMs) forced with a business-as-usual emissions scenario. Throughout the twenty-first century, seasonal extremes of surface-ocean pH are projected to attenuate by  $16\pm 7\%$ , while those for hydrogen ion concentration  $[H^+]$  are projected to amplify  $81\pm 16\%$ . Simultaneously, the seasonal extremes of aragonite saturation state ( $\Omega_{\text{arag}}$ ) are attenuated except in the subtropics where they are amplified. These contrasting changes derive from regionally varying sensitivities of these variables to atmospheric  $CO_2$  and climate change and diverging trends in seasonal extremes in the primary controlling variables. Model projections are consistent with in situ observations at Mediterranean  $CO_2$  seeps. Projected changes will tend to exacerbate impacts of increasing  $[H^+]$  on marine organisms during the summer and ameliorate impacts during the winter, although the opposite holds in the high latitudes. Similarly over most of the ocean, impacts from declining  $\Omega_{\text{arag}}$  are likely to be intensified during summer and dampened during winter, with summer seawater conditions becoming less conducive to calcification over most of the ocean. Marine extreme events in  $[H^+]$  and  $\Omega_{\text{arag}}$  that are not directly tied to the daily and annual cycles are also investigated with idealised simulations in the IPSL-CM6 Earth System Model.

**June 8, 10:40/S1-Oral-13134**

### **Increases in surprising ocean temperatures will challenge the limits of ecosystems and people to adapt**

Andrew **Pershing**<sup>1</sup>, Nicholas R. Record<sup>2</sup>, Bradley Franklin<sup>1</sup>, Brian Kennedy<sup>1</sup>, Katherine E. Mills<sup>1</sup>, Andrew Thomas<sup>3</sup>, Michael Alexander<sup>4</sup> and James Scott<sup>4,5</sup>

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The community of species in an ocean ecosystem and the properties of nearby coastal communities reflect the climate conditions — both the mean and variance — in that region. Novel conditions like the recent “marine heatwaves” can lead to sudden and surprising changes in both the natural and human components of the system. We documented the occurrence of “surprises” — annual mean temperatures that are at least two standard deviations above the mean of the prior 30 years. These unexpected events should become more likely as warming trends increase; however, even accounting for the trends, the recent increase in the frequency of surprising ocean temperatures is surprising. Based on the results of an idealized ecosystem model, we expect that warming trends will degrade the function of marine ecosystems, favoring generalists over specialist and altering productivity and diversity. An analogous model for how humans relate to the ocean quantifies the benefits of projections rather than relying on historical experiences to make decisions.

**June 8, 11:00/S1-Oral-12847**

**Time matters: Longer heatwaves increase mortality of subtidal organisms at sub-lethal temperatures**

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Many of the world's coastal oceans are warming at an unprecedented rate. Recent years have seen an increasing incidence of heatwaves, or short-term temperature extremes, which have led to devastating shifts in some benthic ecosystems. Underlying these changes is the effect of elevated temperatures on the metabolic functioning of the organisms. Yet, these effects are context dependent; duration and intensity of the heatwave will differentially affect taxa. Here, I draw together the results from multiple experiments in which we exposed tropical and temperate sea urchin and gastropod species to heatwaves of varying duration and intensity, measuring physiological and biological responses. Overall, urchins had a more extreme metabolic response to heatwaves than gastropods but were able to recover faster if the duration of heatwave was shorter. In contrast, gastropods tended to depress metabolic responses to higher temperatures and had greater survival in heatwaves of longer duration. Critically, over the longer-term, both urchins and gastropods had elevated mortality at temperatures below their maximum metabolic rate, most likely because of a mismatch between metabolic demands and energy supplies (both reserves and intake). This suggests that the effects of less intense heatwaves can be as devastating to ecosystems as extreme temperatures if they have a duration which exhausts the energetic reserves of individuals.

**June 8, 11:20/S1-Oral-13193**

**Effects of the recent anomalous warming on the lipid and fatty acid structure of zooplankton in the northeast Pacific (Newport, Oregon, USA)**

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A warm anomaly in the upper ocean appeared in the Gulf of Alaska during the calm winter of 2013-2014, spread across the northern North Pacific Ocean, and shifted eastward and onto the Oregon shelf in September of 2014. Following the intrusion onto the shelf, sea surface temperatures increased rapidly and the copepod species composition and lipid structure of the zooplankton community also changed. Zooplankton samples were collected at two stations located on the continental shelf and on the shelf/slope before and after the arrival of the warm anomaly. Prior to the arrival of the warm anomaly the zooplankton community was high in total lipids and the fatty acid composition was strongly separated between the shelf and shelf/slope stations. Following the arrival of the anomalously warm water mass, the zooplankton community was low in total lipids and there were no differences in the fatty acid composition between the shelf and shelf/slope stations.

June 8, 11:40/S1-Oral-12959

## Ocean warming and marine heatwaves: Will these make temperate macroalgae increasingly vulnerable to tropical herbivores?

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The Great Southern Reef (GSR) is a highly productive, temperate reef dominated by large, canopy-forming macroalgae that stretches approximately 8000km along Australia's southern coastline. Climate change is impacting the GSR via gradual warming of nearshore waters and an increase in the frequency of extreme marine heatwaves. Warming has been linked to the strengthening of poleward flowing boundary currents, which bring both warm water and larvae from the tropics into temperate ecosystems, leading to the 'tropicalization' of the GSR. Tropical herbivores including fish and urchins are among the species that are shifting their distribution into the GSR and grazing macroalgal beds. Our study aims to anticipate future threats to the GSR by investigating how warming and marine heatwaves may impact the grazing of macroalgae by the tropical sea urchin *Tripneustes gratilla*. Feeding experiments were used to quantify the effect of warmer temperatures and marine heatwaves on the susceptibility of dominant species of seaweed to urchin herbivory. Seaweed nutritional quality and surface microbiomes were also quantified to explain differences in herbivory. We found contrasting responses to herbivory between macroalgal species, with higher grazing of the common kelp, *Ecklonia radiata*, in heatwave treatments and of the furoid, *Sargassum linearifolium*, under ambient temperature. This implies *Sargassum* may be more resilient to grazing under future conditions, but kelp may be more vulnerable. This research highlights that the direct and indirect responses of macroalgae to climate change may be species specific.

June 8, 12:00/S1-Oral-13028

## Global coral bleaching in the Anthropocene and a call for climate action

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Mass coral bleaching, first documented in the early 1980s, has become one of the most visible marine ecological impacts of global warming. Severe coral bleaching has become more extensive, frequent, and intense with increasing global ocean temperatures. This can be seen both in the acceleration of heat stress events capable of causing mass coral bleaching and in new multi-decadal datasets of bleaching observations. Additionally, while the 1998 and 2010 global coral bleaching events lasted less than 12 months, propagating and teleconnected marine heatwaves in the most recent event caused bleaching from June 2014–May 2017. The global pattern of heat stress and corresponding bleaching, previously seen in 1998 and 2010, was repeated in both 2015 and 2016. The extent and magnitude of this three-year event caused serious damage throughout the tropics. This was at a time when global surface temperature was around 1.0°C above the pre-industrial average – already halfway to the Paris Agreement's 2.0°C target and two-thirds of the aspirational goal of 1.5°C, beyond which the future survival of coral reefs is greatly diminished. This presentation will consider the frequency and patterns of past global heat stress using NOAA Coral Reef Watch's newest multi-decadal record of temperature and heat stress, CoralTemp, along with the two most recently developed global datasets of coral bleaching observations. It also will provide the latest update on the damage to tropical reef ecosystems caused by the 2014-17 global coral bleaching event and discuss the urgent need to limit global warming to protect coral reefs.

**June 8, 13:40/S1-Oral-12741**

### **Increase in global coral bleaching heat stress since 1982**

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Over recent decades, coral reefs have suffered increasing frequency and severity of heat stress due to climate change, resulting in their overall decline worldwide. Mass coral bleaching due to anomalously warm ocean water has become the most significant global contributor to the deterioration of coral reef ecosystems. The third global bleaching event (June 2014-May 2017) was the longest, most widespread, and most damaging global bleaching event on record. It emphasizes the need for understanding long-term changes in ocean temperatures globally, to better understand how more extreme, climate-driven marine heatwaves will affect reef environments and ecosystems. It is well documented that sea surface temperature has increased in most of the global ocean over the past few decades; however, changes in the intensity and spatial coverage of the heat stress that causes coral bleaching on a global scale has not been sufficiently investigated. This study analyzed how the frequency and intensity of heat stress on coral reefs has changed globally since the early 1980s, based on satellite remotely-sensed sea surface temperature measurements. The NOAA Coral Reef Watch satellite bleaching heat stress monitoring algorithm was applied to the NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature version 2 (doISST.v2), a climate data record as well as the newly-developed CoralTemp 5×5km record. Substantial increase in bleaching heat stress, both in magnitude and duration, was identified in most global coral reef areas.

**June 8, 14:00/S1-Oral-12722**

### **Productive instability of coral reef fisheries after a climate-driven regime shift**

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Coral reefs support diverse small-scale fisheries that provide food and employment for tropical coastal communities. Reef ecosystems are vulnerable to anomalous warming events that cause coral mass mortality, provoking benthic regime shifts which can restructure fish communities and alter exploited species biomass. Despite the critical importance of reef habitat to target species, the impacts of thermal heating events on nearshore tropical fisheries are unknown. We compiled over 20 years of artisanal landings data and fishery-independent fish and benthic surveys to examine, for the first time, the long-term impact of the 1998 bleaching event on Seychelles' reef fishery. Using generalized additive models, we analysed landings of reef-associated species groups (*Siganidae*, mixed herbivores, and *Lethrinidae*), and conducted multivariate analyses of fish biomass and habitat composition. From 1994-2016, mean catch per unit effort remained constant yet variation in catches increased dramatically for Siganid and mixed herbivore groups, while Siganid yields doubled. Over the same period, diver observations revealed increased spatial variability of habitat types and target fish biomass, and thus greater patchiness of fishery targets. These changes were driven by strong fish ~ habitat associations following severe bleaching, whereby Siganid biomass increased with macroalgal cover on regime-shifted reefs and biomass of other herbivores increased with structural complexity on recovering reefs. Our results link climate-driven shifts in ecosystem state to higher catch instability, and indicate that disturbed reefs can provide high but irregular catches of herbivorous fishes. The strength of resource ~ habitat associations will dictate how reef fisheries respond to future warming events.

June 8, 14:20/S1-Oral-13180

### Regional scale coral bleaching is a new phenomenon in the Caribbean Lesser Antilles

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Coral bleaching is a stress response to excessive heat. Large-scale bleaching and mortality events have been observed since 1982 and appear to be increasing in both frequency and severity as ocean temperatures rise. However, the lack of bleaching observations prior to 1982 limits our ability to detect and attribute patterns and trends in coral reef bleaching to anthropogenic warming. Here we use a bleaching proxy to reconstruct the last 213 years of regional scale bleaching in the Caribbean Lesser Antilles. Sea surface temperatures in the Lesser Antilles are rising faster than the global average and bleaching was first reported here in 1998. CT scans of long skeletal cores collected from 2 species of massive reef-building corals on Curacao, Barbados, and Martinique reveal discrete, high-density “stress bands”, indicative of bleaching. Our previous work in the tropical Pacific showed the proportion of stress bands in the population of massive corals reflects the extent and severity of bleaching across the reef community. We first validated the proxy on Caribbean species by comparing stress band proportions with observational bleaching data collected after 1995, and applied the proxy downcore to reconstruct bleaching events from 1800 to 2013 AD. Our analysis reveals two previously undocumented bleaching events that occurred on all islands in 1969 and 1981, in addition to recorded events in 1998, 2005 and 2010. However we find no evidence of bleaching prior to 1969. Our results indicate that regional-scale bleaching is a new phenomenon in the Caribbean Lesser Antilles driven by anthropogenic warming.

June 8, 14:40/S1-Oral-12653

### Historical and future projected changes in global marine heatwaves

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Marine heatwaves are important events in oceanic systems that have devastating consequences for ecosystems, causing ecological changes and socioeconomic losses. Prominent marine heatwaves have occurred recently and attracted scientific and public interest, but comprehensive assessments of how these events have been changing globally in the observational record, and are expected to change in the future, is missing. Using ocean temperature observations including daily satellite observations, daily in situ measurements, and gridded monthly in situ-based sea surface temperatures we identify significant increases in marine heatwaves over the past century. We further estimate future changes in marine heatwaves to the end of the 21<sup>st</sup> century, as simulated by the IPCC AR5 global climate model projections. We find that from 1925 to 2016, global averages of marine heatwave frequency and duration have increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heatwave days globally. Importantly, these trends can largely be explained by the increase in mean ocean temperatures. Future projections show significant, and accelerating, increases in MHWs properties into the 21<sup>st</sup> century with many parts of the ocean reaching a near-permanent MHW state by the late 21<sup>st</sup> century, regardless of emissions scenario considered (RCP4.5, 8.5). Comparison with simulations of a natural world, without anthropogenic forcings, indicate that these trends have emerged from the range of natural variability around the year 2000, depending on metric. The implications of this “anthropogenic emergence” on marine ecosystems can be expected to be widespread, significant and persistent.

## **S2: From prediction to projection: The role of seasonal to decadal forecasts in a changing climate**

**June 7, 11:10/S2-Invited-13157**

### **Understanding stakeholder decisions to guide forecasting efforts**

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Impacts of climate change are being felt in fisheries across the globe. While climate-focused forecasts tend to focus on gradual environmental trends over long time horizons, fishing industry participants make decisions on a range of time scales. These decisions may be affected by not only the magnitude of environmental conditions, but also by their timing and variability. We have developed three forecast products relevant to Maine's (USA) lobster fishery: (1) a seasonal forecast of the date when the fishery will switch to its high-landings summer period each year, (2) a multi-annual forecast of the volume of landings expected 6-8 years in the future based on post-larval settlement surveys, and (3) a multi-decadal forecast of the volume of landings over the coming decades based on climate scenarios. While we have demonstrated the technical capacity to make these forecasts, we have also encountered challenges to their acceptance, use, and application by the fishing industry. Currently, we are working with stakeholders in the Maine lobster industry to consider modifications to these forecasts and associated products to enhance their relevance and usability. Through interviews with industry stakeholders (including harvesters, dealers, processors, marketers, and managers), we are developing a systematic understanding of decisions they face, time frames for decision-making, and information they use to guide decisions. Results from these interviews enable us to map decisions to information needs, sources, and gaps in general and to identify avenues for improving existing forecast products or developing new ones.

**June 7, 11:40/S2-Oral-12823**

### **Mechanisms driving seasonal forecast skill in the California Current System**

Michael **Jacox**<sup>1</sup>, Michael Alexander<sup>2</sup>, Steven Bograd<sup>1</sup>, Elliott Hazen<sup>1</sup>, Gaelle Hervieux<sup>2,3</sup>, Nathan Mantua<sup>1</sup>, James Scott<sup>2,3</sup>, Charles Stock<sup>4</sup>, Desiree Tommasi<sup>1</sup>, Robin Webb<sup>2</sup> and Cisco Werner<sup>5</sup>

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The California Current System (CCS) is a biologically productive Eastern Boundary Upwelling System that experiences considerable environmental variability on seasonal and interannual timescales. Given that this variability drives changes in ecologically and economically important living marine resources, predictive skill for regional oceanographic conditions is highly desirable. Here, we assess the skill of seasonal sea surface temperature (SST) forecasts in the CCS using output from multiple Global Climate Forecast Systems, and describe mechanisms that underlie SST predictability. A simple persistence forecast generates considerable skill at short lead times, while skill above persistence derives primarily from predictable wind anomaly patterns associated with moderate to strong ENSO events. During ENSO-neutral conditions, seasonal SST forecasts exhibited no skill above persistence. We find also a strong latitudinal gradient in predictability within the CCS; SST forecast skill is highest off the Washington/Oregon coast and lowest off southern California, consistent with variable wind forcing being the dominant driver of SST predictability. These findings highlight mechanisms that underlie forecast skill as well as sources of limitation in forecast skill. We use them to interpret predictability during the northeast Pacific marine heat wave of 2013-2016, and discuss implications for regional downscaling of seasonal forecasts and for short-term management of living marine resources.



**June 7, 12:00/S2-Oral-12826**

## **Subsurface dynamics leading to decadal predictability in upwelling systems of the North Pacific**

Mercedes Pozo **Buil**<sup>1</sup> and Emanuele Di Lorenzo<sup>2</sup>

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Basin-scale reanalysis products suggest that downstream advection of subsurface water-mass anomalies along the North Pacific Current (NPC) can be exploited for predicting decadal-scale changes of temperature, salinity, nutrients, and oxygen in key upwelling systems of the North Pacific, namely the Gulf of Alaska and the California Current System. However, it is unclear what dynamics generate these subsurface water-mass anomalies and how far upstream along the gyre one can track them for reliable decadal predictions. Using an ensemble of eddy-resolving hindcasts of the Regional Oceanic Modeling System (ROMS) from 1959-2009 over the North Pacific, we (1) diagnose the generating dynamics of subsurface water mass anomalies and (2) quantify the predictability (*e.g.*, deterministic vs. internal variability) associated with the arrival of the anomalies in the upwelling systems. The model results show a region of strong deterministic variance (*e.g.*, predictable) in the core of the NPC and in the sub-polar gyre region, with anomalies generating and propagating from the Kuroshio-Oyashio Extension region. In the model, the anomalies tend to amplify their low-frequency variance as they propagate along the path of the mean circulation. This amplification is the result of anomalous advection acting on the mean gradients of the tracers. South of the NPC the variance is predominantly intrinsic. The regions of intrinsic and deterministic variance inferred from comparing the model ensemble members, are also consistent with comparison against the ECMWF ocean reanalysis. Taken together, these findings provide the physical basis for developing robust decadal forecasts of key ecological and societally-relevant indicators.

**June 7, 12:20/S2-Oral-13056**

## **Forecasting physical drivers of marine ecosystems in the California Current System using a Linear Inverse Modelling approach**

Antonietta **Capotondi** and Prashant D. Sardeshmukh

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The California Current upwelling system (CCS) supports one of the most productive marine ecosystems in the world and is a primary source of ecosystem services for the US. Despite the empirical evidence of ENSO influence upon the US West Coast marine ecosystems, the specific influence of different ENSO events is unclear, and the degree of predictability of different ecosystem drivers for specific tropical Pacific conditions has never been quantified. In particular, it is unclear whether ENSO events with different spatial patterns (*e.g.* Eastern Pacific vs. Central Pacific El Niño events) impact the local climate drivers along the CCS in different ways. In addition, the optimal tropical forcing may differ from “canonical” El Niño patterns, so that only the events with a large projection on the optimal forcing can be expected to significantly affect the target region. In this study, we first use a combination of multiple linear regression and Singular Value Decomposition to first determine the tropical conditions that optimally drive sea surface temperature (SST) and sea surface height (SSH) anomalies in the CCS region, then develop a suite of Linear Inverse Models that include different combinations of oceanic and atmospheric variables to investigate the predictability of those quantities along the CCS at seasonal to interannual timescales. Results are compared and contrasted with predictability estimates obtained from the North American Multi-Model Ensemble (NMME).

**June 7, 14:00/S2-Oral-13063**

### **Subdecadal modulation in the Pacific in 2000s**

Takashi **Mochizuki**<sup>1</sup>, Masahiro Watanabe<sup>2</sup> and Masahide Kimoto<sup>2</sup>

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Further process understanding of climate variability and predictability is a key contributor to enhancing our ability of decadal prediction. Subdecadal modulation in the upper ocean heat content relevant to global warming hiatus is observed over the tropical Pacific in 2000s, in a different manner from other decades. Dynamical ocean response to the strong subdecadal modulation in the Pacific trade wind works to keep warm and cold tendencies in the western and eastern Pacific Oceans, respectively, and consequently it can contribute to slow down of global warming. Our CMIP5 decadal hindcasts with initialization insufficiently reproduce the subdecadal modulation even a few years in advance, particularly due to low skill in hindcasting the strong trade wind observed in mid-2000s. Sensitivity experiments of a coupled climate model suggest that the strong trade wind can be largely contributed by high sea surface temperature over the tropical Atlantic Ocean, which is part of the positive peak of the Atlantic Multidecadal Oscillation.

**June 7, 14:20/S2-Oral-13083**

### **Subseasonal forecast of surface water conditions in Chesapeake Bay using a hybrid approach**

Fernando Gonzalez **Taboada**<sup>1, 2</sup>, Keith Dixon<sup>1</sup>, Barbara Muhling<sup>2</sup>, Desiree Tommasi<sup>3</sup>, Mary-Jo Nath<sup>1</sup>, Vincent Saba<sup>4</sup>, Gabriel Vecchi<sup>2</sup> and Charles Stock<sup>1</sup>

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Estuaries provide key ecosystem services like nutrient cycling, food provision and cultural and recreational uses that confer them a high socioeconomic value. At the same time, these ecosystems are subject to important human impacts associated with eutrophication, overexploitation and climate change. The small extent of estuaries and the mélange of oceanic and terrestrial influences represent a major challenge for traditional management strategies. The emerging field of ecological forecasting extends current models by incorporating forecasts of environmental conditions to inform management decisions. Here, we present a hybrid empirical-dynamical approach to forecast surface water conditions in Chesapeake Bay at a one-month lead time. The approach builds upon seasonal forecasts of atmospheric temperature based on ensemble simulations of the GFDL Global Climate Model forecast system FLOR. Large scale forecasts of surface temperature are translated to anomalies at the estuary scale using Empirical Statistical Downscaling (ESD). These anomalies serve as input to a local spatial statistical model of the evolution of temperature conditions in the bay, the output of which leads to an improvement of short term forecast skill above persistence. Temperature forecasts were complemented with predictions of variability in salinity fields based on river discharge to complete the description of surface conditions. While seasonal climate predictability is modest in this region, results show significant skill (anomaly correlation coefficients above 0.5) and support the use of hybrid approaches to take advantage of the strengths of dynamic forecasts and statistical techniques. The potential development of local ecological forecasts applications is discussed.

**June 7, 14:40/S2-Oral-12750**

### **Seasonal forecasts of hypoxia and ocean acidification in Washington and Oregon Waters**

Samantha **Siedlecki**<sup>1</sup>, Simone Alin<sup>2</sup>, Albert Hermann<sup>2, 3</sup>, Nicholas Bond<sup>2, 3</sup>, Isaac Kaplan<sup>4</sup>, Emily Norton<sup>3</sup>, Jan Newton<sup>5</sup>, Burke Hales<sup>6</sup> and Richard Feely<sup>2</sup>

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Ocean acidification and hypoxia of coastal waters are of increasing concern to local fisheries. In the Pacific Northwest (PNW), direct effects have been observed on the \$100 million shellfish industry. The ability to predict the degree of acidification as well as relevant indices of impact for the shellfish industry could be of considerable benefit to these stakeholders. Through the design of biogeochemically relevant tracers and implementation in high-resolution models, regional simulations can improve our understanding of processes difficult to observe, investigate relationships between the ecology of marine organisms and ocean health, and generate forecasts and projections of changes to the region. For example, seasonal forecasting is now possible in the region with JISAO's Seasonal Coastal Ocean Prediction of the Ecosystem, J-SCOPE, (Siedlecki *et al.*, 2016). We have examined model performance and predictability for sea surface temperature (SST), bottom temperature, bottom oxygen, pH, and aragonite saturation state ( $\Omega$ ) along the Washington and Oregon coasts. Results indicate J-SCOPE forecasts have measurable skill on seasonal timescales, for variables relevant to management decisions for fisheries, protected species, and ecosystem health. Skill assessment and quantification of model performance focus on key variables of interest for local shellfish species: examples include bottom oxygen for adult crab and  $\Omega$  for oyster and crab larvae. The resulting habitat models have more predictive skill when formulated with ocean variables that perform well. The J-SCOPE team is now working on implementing a forecast specifically targeting key shellfish species in the region. We plan to showcase our initial results of these pH forecasts and targeted products, including their forecast skill.

**June 7, 15:00/S2-Oral-13206**

### **Seasonal to multi-annual marine biogeochemical prediction using GFDL's Earth System Model**

Jong-Yeon **Park**<sup>1,2</sup>, Charles Stock<sup>2</sup>, Xiaosong Yang<sup>2</sup>, John P. Dunne<sup>2</sup>, Anthony Rosati<sup>2</sup>, Jasmin John<sup>2</sup> and Shaoqing Zhang<sup>3</sup>

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While physical ocean prediction systems routinely assimilate observations and produce seasonal to decadal forecasts, ocean biogeochemical (BGC) prediction systems are less mature due to additional challenges. These include insufficient global-scale BGC observations to inform model initialization, uncertainties from both physical and BGC processes in earth system models, and properties of BGC variables that challenge data assimilation approaches (*e.g.*, non-Gaussian, complex patterns of cross-correlation). A first impediment, however, is the high BGC sensitivity to transient momentum imbalances that arise during physical data assimilation. In this study, we develop a strategy to robustly integrate the GFDL's ocean BGC model with the ensemble coupled-climate data assimilation (ECDA) system used for GFDL's seasonal to decadal global climate predictions. The ocean and atmosphere data constraints in the assimilation system are optimally modified to reduce BGC biases caused by momentum imbalances while retaining the information of observed physical states. We then performed retrospective prediction runs by initializing the model with the output from our ECDA run coupled with BGC model and investigated seasonal to multi-annual prediction skills of nutrient anomalies, oxygen, phytoplankton and zooplankton over 1991 to 2016. We found that BGC variables generally show a higher and longer-term predictability than sea surface temperature although predictability varies regionally and with initialization month. While the predictability results here suggest a promising strategy of using earth system models for future operational BGC prediction systems, assessment of BGC predictions against satellite datasets shows a considerable gap between potential predictability and achieved prediction skills. Opportunities to close this gap will be also discussed.

**June 7, 15:20/S2-Oral-12672**

### **Exploring the potential for a North West European shelf seas ecosystem seasonal forecast**

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Sustainable management and utilisation of the North West European Shelf Seas (NWS) could benefit from reliable forecasts of the marine ecosystem on monthly-to-seasonal timescales. The Met Office Global Seasonal forecast system (GloSea5) has now attained significant levels of predictability of the dominant mode of climate variability of the European climate –the North Atlantic Oscillation. This provides the basis to possible seasonal forecasts of the physical environment of the NWS. In some regions of the world, it is possible to make seasonal predictions directly from on the global forecasting system, however, this is not possible for the NWS – GloSea5 does not capture important aspects of the NWS oceanography due to the spatial resolution of its global ocean model component, and the (current) absence of dynamic tides which dominate the NWS. Furthermore, GloSea5 does not have a biogeochemistry component. We show that skilful seasonal forecasts can be produced for some physical properties of the NWS, by empirically downscaling GloSea5 forecasts of the North Atlantic Oscillation. To investigate the potential of more detailed seasonal forecasts of the NWS ecosystem, we dynamically downscale GloSea5 hindcasts with a regional ocean model coupled to a shelf seas ecosystem model ERSEM. We show a case study to assess the ability of model to distinguish between the evolution of chlorophyll in two contrasting years with early and late onset of seasonal stratification. Finally we draw together the results to consider the prospects for NWS seasonal forecasting, and highlight research priorities.

**June 7, 15:40/S2-Oral-12725**

### **Seasonal and decadal forecast development for a multi-species pelagic longline fishery**

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The abundance and distribution and hence availability of highly migratory tuna and billfish species to fisheries are known to be strongly influenced by oceanographic conditions. The five target species of the Australian east coast longline fishery (albacore, bigeye, yellowfin tuna, striped marlin, broadbill swordfish) have a wide distribution outside the Australian EEZ, but the influence of oceanographic factors within the fishery region and the surrounding south-west Pacific region is poorly understood, creating uncertainty in current management arrangements. The waters off the east coast of Australia are also experiencing rapid climate change, with range expansion already observed for many coastal and pelagic fish species. Changes in distribution over the 21st century are also projected for these five species in eastern Australia and the wider Pacific.

The Australian longline management agency and the fishing industry are seeking insight into past, current and potential future oceanographic and environmental impacts upon (i) the spatial and temporal distribution and level of longline catches, catch rates, fishing effort and fish sizes, and (ii) the interactions between focal species in the domestic and international fisheries. In previous work we have developed habitat models and seasonal forecasting approaches for a range of species in Australia, including southern bluefin tuna, using the Bureau of Meteorology's POAMA model, which produces skillful seasonal forecasts of key variables at lead times of up to four months. This new three year project will provide insights into potential long term changes in the longline fishery that may result from climate change, and deliver forecasting capability on seasonal and decadal time scales for the five species targeted in the fishery. We will utilise new high resolution models for seasonal forecasting (ACCESS-S1) and our state-of-the-art decadal forecasting capability. This effort will support decision making by Australian and south-west Pacific managers and fishers, and build capability for operating in a rapidly changing region.

**June 7, 16:20/S2-Oral-12400**

### **Predicting ecological responses to climate variability with a dynamic Bayesian network model**

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The Gulf of Mexico is an ecologically and economically important ecosystem that is affected by a variety of natural and anthropogenic factors. These complex and interacting stressors, together with the dynamic environment of the Gulf, present challenges for the effective management of its resources. With the recent adoption of Bayesian networks in ecology, few assumptions can be made about the system and complex interactions can be discovered and quantified from data. In this study, we apply Bayesian network models with a varying number of hidden variables to account for uncertainty when modeling species dynamics. From these models, we predict focal ecosystem components within the Gulf. The predictive ability of the models varied with their structure. The model that performed best was parameterized through data-driven learning techniques and accounted for multispecies associations and their interactions with human and natural pressures over time. Then, we altered sea surface temperature in the selected model to explore the response of different variables to increased temperature. Most species were predicted to decline as temperature increased, however, the magnitude of predicted decreases varied by species due to heterogeneity in driving factors and their spatial overlap. Our findings suggest that due to varying species sensitivity to drivers, changes in temperature will potentially lead to trade-offs in terms of population productivity. We were able to discover interactions between species and their environment and show how sensitive these relationships are to climate perturbations, which might provide strategic advice on the potential future response of the system to increasing temperature.

**June 7, 16:40/S2-Oral-12998**

### **Envisaging the future distribution of North Atlantic bluefin tuna across seasonal, decadal and centennial scales**

Mark R. **Payne**<sup>1</sup>, Daniela Matei<sup>2</sup> and Brian R. MacKenzie<sup>1</sup>

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Modern climate prediction models have reached a point where, in some parts of the world and for some variables, meaningful predictive skill spans lead times from one month to 10 years and in some cases more. Such predictions therefore span multiple decision-making time-scales and form a natural bridge to the climatic timescales associated with projection models. We illustrate how this information can be used in a biological context using the summer distribution of North Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus 1758) as an example. Recent observations of this species east of Greenland in Denmark Strait and tagging data have shown that the range of this species is constrained by thermal limits. We examine the skill of climate prediction models to predict this thermally constrained habitat across multiple time-scales, from seasonal to climatic. We found skill over and above a persistence forecast (*i.e.* assuming no change) out to a decade. We demonstrate that recent changes in distribution in this region, including the appearance of tuna, could therefore have been predicted with similar lead times. We show good agreement between our forecasts and catch records in this region. Finally, we couple these results to climate projection models to assess potential future distribution scenarios and thereby develop a picture of the distribution of this species ranging across timescales from one month to 80 years. We discuss the applications of these results for use in the management and conservation of this species.

**June 7, 17:00/S2-Oral-13039**

### **Seasonal forecasting of Pacific hake distribution in the California Current Ecosystem**

Michael J. **Malick**<sup>1</sup>, Mary Hunsicker<sup>2</sup>, Melissa Haltuch<sup>1</sup>, Sandy Parker-Stetter<sup>1</sup>, Isaac Kaplan<sup>1</sup>, Aaron Berger<sup>2</sup>, Kristin Marshall<sup>1</sup>, Richard Brodeur<sup>2</sup>, Samantha Siedlecki<sup>3</sup>, Nicholas Bond<sup>4</sup>, Albert Hermann<sup>4</sup>, Emily Norton<sup>4</sup> and Jan Newton<sup>5</sup>

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The spatial distribution of marine fish populations provides critical information about the availability of a population to monitoring, fisheries, and management actions. Yet, there are often substantial uncertainties associated with the mechanisms driving fish distribution that can limit the ability of decision-makers to respond to rapidly changing ecosystem conditions and resulting shifts in fish distribution. This is particularly true for migratory species, such as Pacific hake (*Merluccius productus*), because their seasonal distribution changes greatly across space and time. In this research, we develop seasonal forecasting models of Pacific hake spatial distribution within the California Current Ecosystem, with the goal of improving survey monitoring design and informing future management procedures. We first test mechanistic hypotheses regarding the drivers of hake spatial distribution using statistical models, *in situ* oceanographic observations, and hake survey distribution data. We then use the J-SCOPE ocean forecast system to develop 1 to 6 month lead-time forecasts of Pacific hake distribution based on seasonal projections of ocean conditions in the California Current Ecosystem. The forecasting models developed here address research questions that can inform current hake management, combining fundamental ecosystem-based knowledge with management decisions. Further, this research provides an opportunity to improve our understanding of the ecological mechanisms underlying marine fish spatial dynamics and to evaluate how understanding ecological mechanisms can improve the transboundary management of the commercially valuable Pacific hake stock.

**June 7, 17:20/S2-Oral-13186**

### **Incorporating recruitment-environment linkages into stock assessment models for Alaskan groundfish with application to population projections in a changing climate**

Ashley Weston<sup>1</sup>, Gavin **Fay**<sup>1</sup> and Carey R. McGilliard<sup>2</sup>

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Synchrony in recruitment trends among species with similar early life history traits suggests environmental conditions can influence recruitment success for many species simultaneously, and was identified among flatfish species in the Gulf of Alaska (GOA) that move from the slope to the shelf as larvae. Previous studies have linked recruitment of these species to an index heavily driven by sea surface height (SSH). Stock assessment models have been used to incorporate recruitment-environment linkages and to forecast population dynamics under future climate pathways. However, little is known about whether effective tools exist to determine whether modeled linkages are correct. We evaluated the accuracy of three model selection tools (AIC, hold-out cross-validation, and Mohn's retrospective statistic) to distinguish among modeled recruitment-environment relationships. We then forecasted GOA flatfish dynamics under IPCC climate scenarios, including a linkage between SSH and recruitment. We included models where recruitment-environment linkages were correctly- or mis-specified to identify harvest policies that were robust to both future climate pathways and mis-specification of recruitment-environment linkages. Results show that none of the model selection tools are able to correctly select a model with no recruitment-environment linkage when none exists. However, given that a linkage exists, AIC is able to correctly select whether it influences carrying capacity or productivity. Choosing a mis-specified model led to bias in estimates of some parameters, including maximum sustainable yield. We will discuss the impact of these biases on population forecasts and the ability of current harvest policies to maintain sustainable population trajectories for GOA flatfish.

June 7, 17:40/S2-Oral-12787

## Forecast skill for predicting distribution shifts: A retrospective experiment for marine fishes in the Eastern Bering Sea

James Thorson

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Forecasting distribution shifts under novel environmental conditions is a major task for fisheries scientists and managers. Researchers often forecast distribution shifts by: predicting from an empirical relationship between a summary of distribution (population centroid) and annual time-series (“Annual Regression”, AR); or fitting a habitat-envelope model to historical distribution and forecasting given future environmental conditions (“Habitat Envelope”, HE). However, surprisingly little fisheries research has measured predictive skill for forecasts of distribution shifts using retrospective analysis of historical data. I demonstrate the role of retrospective skill testing by evaluating forecasts of poleward movement over 1, 2, or 3-year periods for 20 fish and crab species in the Eastern Bering Sea. I specifically introduce an alternative vector autoregressive spatio-temporal (VAST) model and compare skill for AR, HE, and VAST forecasts. Results show that the HE forecast has lower predictive skill than forecasting that distribution is stationary in the future (a “persistence” forecast). Meanwhile, the AR explains 2-6% and VAST explains 8-25% of variance in poleward movement, and both have better performance than persistence forecast. HE and AR both generate forecast intervals that are too narrow and therefore contain the observed shifts in distribution less often than expected, while the VAST model has appropriate width for forecast intervals. Retrospective analysis is an important tool to test predictive skill for alternative statistical methods, and should be regularly used to evaluate skill for forecasts of distribution shifts.

June 7, 18:00/S2-Oral-13054

## Forecasting fishery trends in a warming ocean: A modeling framework using early life stages of the American lobster

Noah G. Oppenheim<sup>1,2</sup>, Richard A. Wahle<sup>1</sup>, Damian C. Brady<sup>1</sup> and Andrew Pershing<sup>3</sup>

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One challenge of forecasting recruitment trends for long-lived species in a variable environment is to model changing conditions at fine enough spatial scale to characterize diverging recruitment trends over a species' geographic range. The population of the American lobster (*Homarus americanus*), comprising the most valuable fishery in the US, has moved northward in response to warming seas, resulting in fishery collapse in southern New England and dramatic expansion in the north. Here we describe recent enhancements of a fishery recruitment forecasting model that employs the American Lobster Settlement Index (ALSI), a comprehensive annual diver-based survey that quantifies the abundance of young-of-year lobsters repopulating coastal nurseries each year. The novel aspect of this model is that along one of the steepest latitudinal temperature gradients in the world, it incorporates local variability in environmental indicators to scale growth, natural mortality, and associated uncertainty. We developed forecasting models for 10 study areas along the steep coastwise environmental gradient from southern New England, USA to Atlantic Canada, and models performed well in hindcast validation for 9 of these areas. Our models accurately predicted the collapse of lobster stocks in southern New England, as well as increases in the Gulf of Maine (GoM). Forecasts for the GoM suggest moderate declines in fishery recruitment within the next decade, but no sign that southern New England will rebound. We anticipate multi-year projection models such as this will help stakeholders buy time to make informed decisions on the management of this iconic fishery.

## **S3: Carbon uptake, ocean acidification, and ecosystems and human impacts**

**June 5, 11:00/S3-Invited-12715**

### **A change in the forecast: Ocean carbon uptake over the next decade**

Nicole **Lovenduski**<sup>1</sup>, Stephen G. Yeager<sup>2</sup>, Keith Lindsay<sup>2</sup> and Matthew Long<sup>2</sup>

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Over the last decade, the global ocean absorbed approximately 30% of the carbon dioxide emissions from fossil fuels, industry, and land-use change. Quantifying future changes in this important climate service is essential for the development of carbon dioxide emissions management strategies. Here, we present some promising first results that indicate regional predictability in ocean carbon uptake on interannual to decadal timescales. Our study quantifies predictability and predictive skill in air-sea CO<sub>2</sub> flux across the globe using output from the Community Earth System Model Decadal Prediction (CESM-DP) system and observationally-based estimates of air-sea CO<sub>2</sub> flux. Standard anomaly correlation analysis of CESM-DP retrospective forecasts reveals significant predictability in CO<sub>2</sub> flux in the California Current, eastern subtropical south Pacific, and North Atlantic basins on forecast lead times of 1-6 years. Mean square skill score statistics suggest that model initialization engenders predictability of CO<sub>2</sub> flux in these regions. In contrast, we find low interannual to decadal predictability of CO<sub>2</sub> flux in the open Southern Ocean. We further analyze output from CESM-DP to determine the mechanisms causing or inhibiting predictability and predictive skill in ocean carbon uptake.

**June 5, 11:30/S3-Oral-13116**

### **Variability and trends in ocean carbon uptake: 1981-2016**

Galen A. **McKinley** and Amanda Fay

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Cumulatively since the preindustrial era, the ocean has absorbed significant anthropogenic carbon, quantitatively equivalent to 41% of fossil fuel and cement emissions. Under a high emission scenario, the global sink is expected to grow with rising emissions through mid-century, but this growth is not spatially homogenous. Some regions are expected to see strong sink growth while others should experience stagnation. In this presentation, we update our previous analysis of observed change in the ocean carbon sink on timescales from interannual to multidecadal in 17 basin-scale biomes. Based on SOCATv5 pCO<sub>2</sub> data for 1981 and 2016, we find strong long-term growth of the ocean carbon sink only in the North Pacific. In other regions, including the Southern Ocean and the North Atlantic, variability on decadal timescales is the dominant signal. Change in the carbon sink is considered in the context of large-scale modes of climate variability and are compared to predictions from the Community Earth System Model Large Ensemble.



June 5, 11:50/S3-Oral-13124

## Requirements-driven global ocean observing system for Ocean Acidification and Deoxygenation

Maciej **Telszewski**<sup>1</sup>, Masao Ishii<sup>2</sup>, Kim Currie<sup>3</sup>, Artur Palacz<sup>1</sup> and Albert Fischer<sup>4</sup>

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Ocean carbon and biogeochemistry observations aimed at quantifying the adverse impacts of currently observed variability on the ecosystem are conducted at national, regional and global levels. These measurements enable the understanding and quantification of processes such as ocean acidification, ocean deoxygenation, eutrophication, air-sea fluxes and remineralization. The International Ocean Carbon Coordination Project (IOCCP), in collaboration with other international bodies such as GOA-ON and GO2NE, leads the biogeochemistry community towards a harmonized and integrated strategy for the multi-disciplinary Global Ocean Observing System (GOOS) aimed at delivering essential ocean information to the society. These efforts entail reconciling the operational service-oriented and research-oriented elements of the value chain starting from ocean observations, developing information products, informing assessments, model forecasts and future projections thus supporting knowledge-based management and informed policy-making. IOCCP is responsible for capturing and development of requirements for sustained observations. This process has been captured in GOOS Essential Ocean Variables (EOVs) and associated specification sheets. Aspects such as spatio-temporal scales of related phenomena, ranges of signal variability, geographical distribution and intensity of associated processes and more are combined with first-hand description of our current observing capacity as well updated status of data and information product delivery chains, allowing for multi-factoral gap analysis. In this contribution we would like to update the community on the status of coordination of ocean observations with respect to Inorganic Carbon and Oxygen, taking into account a complex myriad of spatio-temporal scales of the distinct biogeochemical phenomena of interest and the ever-growing array of corresponding observing elements.

June 5, 12:10/S3-Oral-13184

## Impact of local biogeochemical processes and climate variability on ocean acidification in the Bering Sea

Darren J. **Pilcher**<sup>1,2</sup>, Danielle M. Naiman<sup>2,3</sup>, Jessica N. Cross<sup>2</sup>, Albert Hermann<sup>1,2</sup>, Samantha Siedlecki<sup>4</sup>, Georgina A. Gibson<sup>5</sup> and Jeremy T. Mathis<sup>6</sup>

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Ocean acidification (OA) results from the oceanic uptake of anthropogenic CO<sub>2</sub>. The Bering Sea is highly vulnerable to OA due to naturally cold, low carbonate concentration waters. Expected negative impacts of OA to marine organisms therefore pose a significant threat to this highly productive marine ecosystem. However, harsh weather conditions within this rapidly changing environment hamper longterm observational monitoring. Well-validated biogeochemical models are a useful tool to help support observational efforts and provide skillful projections of OA on multiple timeframes. We add carbonate chemistry to a regional biogeochemical model of the Bering Sea to explore the underlying mechanisms driving carbon dynamics over a decadal hindcast (2003-2012). The results illustrate that local processes generate considerable spatial variability in the biogeochemistry and vulnerability to OA of Bering Sea shelf water. Substantial seasonal biological productivity maintains highly supersaturated carbonate saturation states ( $\Omega$ ) on the outer shelf, whereas freshwater runoff from major river systems with relatively corrosive water decrease  $\Omega$  to values below 1 on the inner shelf. Over the entire decadal hindcast, a substantial increase in ocean carbon uptake generates a decrease in annual surface  $\Omega$  of 0.2-0.4 units. This OA signal is robust throughout relatively warm (2003-2005) and cold (2010-2012) temperature regimes, which are known to greatly impact the Bering Sea ecosystem. This suggests that the OA signal is distinguishable from natural variability on decadal timeframes, even within a regional setting during a period of substantial climate-driven variability.

**June 5, 12:30/S3-Oral-12636**

### **Changing ocean acidity as a modulator of atmospheric biogeochemistry and climate**

Frances E. Hopkins<sup>1</sup>, Parvatha Suntharalingam<sup>2</sup>, Marion **Gehlen**<sup>3</sup>, and all participants of GESAMP Working Group 38 ocean acidification and trace gases workshop.

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<sup>3</sup> Laboratoire des Sciences du Climat et de l'Environnement Institut Pierre Simon Laplace, Orme des Merisiers, Gif-sur-Yvette cedex, France

The surface oceans contain a rich variety of biogenic trace gases that readily exchange with the lower atmosphere, and strongly influence the Earth's atmospheric chemistry and climate. They are formed via direct biological processes including algal and microbial production, and indirectly through photochemical or microbial interactions with dissolved organic matter. They include familiar greenhouse gases (*e.g.* nitrous oxide, N<sub>2</sub>O and methane, CH<sub>4</sub>) with well understood effects on global radiative forcing, as well as a cocktail of volatile organic carbon-, sulfur-, nitrogen- and halogen-containing compounds that influence marine aerosol formation and cloud-related processes, and the cycling of tropospheric oxidants. Ocean acidification (OA) is expected to affect a range of biological and biogeochemical processes. Thus it is likely to influence the production and sea-air flux of biogenic trace gases, with potential significant feedbacks on the atmosphere and climate. We have a solid foundation of experimental data for dimethyl sulfide (DMS), a trace gas which consistently responds to OA. Some of this existing data has been incorporated into Earth system models which show that the magnitude of DMS response is enough to have a significant effect on the future climate. Less is known of other gases. The production of N<sub>2</sub>O may be influenced by direct effects on microbially-driven processes and indirect effects on organic matter availability within the marine nitrogen cycle. For other marine biogenic gases our understanding is more limited. In this talk, we explore the current understanding in this field, identify the key knowledge gaps and make recommendations for future research.

**June 5, 12:50/S3-Oral-13249**

### **Microbial carbon sequestration in the ocean and climate change**

Nianzhi **Jiao**, Louis Legendre and Richard Rivkin

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Climate change is altering oceanic biogeochemistry and ecosystems, but the mechanisms behind the phenomena remain unclear at ecosystem level. Biological processing of carbon is a key ecosystem process, it is sensitive to climate change, and is directly linked to a suite of ocean conditions. Carbon sequestration is an important earth-ecosystem service provided by the ocean. In addition to the well-known ocean biological carbon pump which transports organic matter from surface to the deep ocean and seabed, the recently characterized depth-independent microbial carbon pump (MCP) which transforms organic matter from biologically available to unavailable forms and sequester carbon throughout the water column. The MCP provides a robust approach to an enigma raised half a century ago - the formation of a long-lived refractory dissolved organic carbon reservoir in the deep ocean which is equivalent the carbon inventory of atmospheric CO<sub>2</sub>. A Scientific Committee for Oceanic Research (2008-2014) working group made significant progresses in developing the MCP framework, followed by numerous studies with intriguing insight. Given the urgent demand of knowledge on climate change and its regulation mechanisms, a joint working group under the Pacific Ocean Science Organization (PICES) and the International Council for the Exploration of the Sea (ICES) was formed in 2015 (WG 33 for PICES and WGCCBOCS for ICES) on the theme of climate change and biologically-driven ocean carbon sequestration. This talk summarizes current understanding of ocean carbon sequestration processes, mechanisms, and their consequences, and considers the impact of important climate forcings on carbon sequestration.

**June 5, 14:20/S3-Oral-12696**

### **Making Ocean Acidification Data Accessible and Useable for Coastal Managers**

Libby **Jewett**<sup>1</sup>, Simone Alin<sup>2</sup>, Adrienne Sutton<sup>2</sup>, Shallin Busch<sup>1, 3</sup>, Samantha Siedlecki<sup>4</sup>, Dwight Gledhill<sup>1</sup> and Kirsten Isensee<sup>5</sup>

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The NOAA Ocean Acidification Program has made a concerted effort to promote data accessibility and the development of information products and online tools to assist coastal managers and policy makers with decision making related to ocean acidification (OA). OA is caused by the absorption of anthropogenic CO<sub>2</sub> by the ocean and will likely have increasing impacts on marine ecosystems. The spectrum of data products funded by the OA Program to promote data dissemination and uptake of management-relevant information include 1) infographics that summarize the various factors influencing OA in particular regions, 2) online tools that enable coastal managers to visualize how OA will manifest in their region over time and how OA may affect important fisheries, 3) seasonal forecast models that predict how OA conditions might affect particular commercial fishery sectors, 4) information products and assessments for coral reef managers, 5) regional OA data portals with built-in data visualization tools, and 6) a collaboration website by which managers can access and contribute OA-related information and have conversations with the OA community. In addition, we now are thinking about how to make OA data available to meet the needs of Sustainable Development Goal 14.3 and to report towards this indicator. These various products will be showcased to demonstrate the value of translating raw data into information that can be utilized by a wide range of stakeholders.

**June 5, 14:40/S3-Oral-12537**

### **Bridging the gap between ocean acidification impacts and economic valuation “From Sciences to Solutions: Ocean acidification impacts on ecosystem services – Case studies on coral reefs”**

Nathalie **Hilmi**<sup>1</sup> and Peter W. **Swarzenski**<sup>2</sup>

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Ocean acidification, often called “the other CO<sub>2</sub> problem”, is a consequence of an increased release of anthropogenic carbon dioxide. The acidity of the oceans has increased by about 30% since the beginning of the industrial era, and may increase by more than 150% by the end of the century. This increase in acidity impacts the lives and well-being of many marine organisms and can also disrupt coastal and marine ecosystems and the services they provide.

The workshops on the economics of ocean acidification were born from the Monaco Declaration (2008), which aimed to raise awareness among policy-makers on the issues of ocean acidification and encourage interdisciplinary research efforts in this area. Organized by the Scientific Center of Monaco and the IAEA Environment Laboratories, this edition brought together about sixty experts in natural and social sciences, from 23 countries with highly diverse and complementary skills and experiences.

It was dedicated to the solutions to be developed in order to save coral reefs threatened by ocean acidification but also by other global or local stressors. The workshop is truly multidisciplinary in character, involving natural sciences such as biology and chemistry and social and human sciences, such as economics and sociology, anthropology. Participants addressed the workshop topic through the lenses of their own disciplines in order to highlight interconnections and propose comprehensive solutions.

**June 5, 15:00/S3-Oral-12600**

## **Anthropogenic carbon increases and biological impacts in the California Current Ecosystem**

Richard **Feely**<sup>1</sup>, Brendan Carter<sup>2</sup>, Nina Bednarsek<sup>3</sup>, Simone Alin<sup>1</sup> and Dana Greeley<sup>1</sup>

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The continental shelf region off the Washington-Oregon-California-British Columbia coast is exposed to water with increasing concentrations of anthropogenic CO<sub>2</sub> (C<sub>anthro</sub>) from exchanges with the atmosphere. We used the 2<sup>nd</sup> order polynomial described in Feely et al (2016) to determine the spatial variations of C<sub>anthro</sub> in the California Current Ecosystem based on cruise data sets from 2007, 2011, 2012, 2013 and 2016. Our results show large spatial differences in C<sub>anthro</sub> in surface waters along the coast with the lowest values (40-45 μmol kg<sup>-1</sup>) in strong upwelling regions of off northern California and southern Oregon and higher values (50-65 μmol kg<sup>-1</sup>) to the south in the California Bight region and to the north along the Washington and British Columbia coasts. C<sub>anthro</sub> increases at a rate of approximately 1 μmol kg<sup>-1</sup> yr<sup>-1</sup> in surface waters, and decreases to values of about 0.3 μmol kg<sup>-1</sup> yr<sup>-1</sup> at depths near 400 m. The remaining enrichment in subsurface dissolved dioxide concentrations is either due to respiration processes in the water that was upwelled and transported to coastal regions or respiration processes that occur locally during the course of the upwelling season. The uptake of C<sub>anthro</sub> has caused the aragonite saturation horizon to shoal by approximately 30-50 m since preindustrial period so that the undersaturated waters are well within the regions that affect the biological communities on the continental shelf. We will provide new findings that support the importance of temperature and ocean acidification as two major stressors controlling distribution of pelagic pteropods in this ecosystem.

**June 5, 15:20/S3-Oral-12786**

## **Projecting the fate of fish stocks in a changing ocean – The future of Northeast Arctic cod under ocean acidification and warming**

Martina H. **Stiasny**<sup>1</sup> and Anna-Marie Winter<sup>2</sup>

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The Northeast Arctic cod stock has a long-standing fishing history and is currently the largest cod stock in the world. At the same time, the Arctic waters are predicted to be globally strongest effected by climate change. While the impact of rising temperature on arctic fish has been thoroughly investigated, understanding the effects of ocean acidification are still hampered by the lack of experimental data.

In this study, we incorporate a unique set of experimental mortality estimates for Atlantic cod larvae under ocean acidification into a temperature dependent population model. While we believe that ocean acidification mainly effects juvenile mortality, ocean warming is considered to affect both juvenile production as well as individual growth. We analyse the combined effects of ocean warming and acidification on the cod population given 1) different shapes of the CO<sub>2</sub> response function to climate change and 2) different temperature optima of recruitment production.

We show that temperature induced productivity can offset ocean acidification effects, but only on the short-run in the likely case of a temperature optima in the stock-recruitment function. We discuss our results in context of a sustainable management of the Northeast Arctic cod.

**June 5, 15:40/S3-Oral-12865**

### **Dialogues between scientists and stakeholders on making ocean acidification a policy focus in Japan**

Tomohiko Tsunoda and Nobuko Nakamura

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In 2015, OPRI-SPF led the launch of a 5-year program of research on ocean acidification. Through this program, we aim to raise notice widely about ocean risks and develop policy recommendations in order to fill the difference in the recognition of ocean acidification among various stakeholders. As a part of this program, in collaboration with scientists in Japan, we submitted the following proposals in 2017 on ocean acidification issues for inclusion in Japan's next Basic Plan on Ocean policy.

- 1: Promotion of understanding based on scientific knowledge and consideration of countermeasures
- 2: Increase international contributions
- 3: Promotion of emission reduction measures of carbon dioxide
- 4: Promotion of Public Awareness Activities

Regarding the promotion of public awareness activities, we are also developing a website called "Marine Crisis Watch" and working with high-school students to enhance monitoring in coastal areas.

**June 5, 16:00/S3-Oral-12968**

### **Temporal variability of carbonate parameters in Guiguiwanen Channel, Bolinao, Pangasinan**

Mary Chris Lagumen and Maria Lourdes San Diego-McGlone

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Several factors affect the carbonate system in coastal waters. These includes seasonally varying salinity, organic loading from rivers and primary production from phytoplankton blooms. Variation in carbonate parameters is seasonally influenced by freshwater inputs as seen in Florida Bay. The study aimed to assess the seasonal (wet and dry), tidal (spring and neap), diurnal (24-hours) variability of the carbonate parameters in Guiguiwanen Channel in Bolinao, Pangasinan, an area influenced by fish farming. Observations and measurements made in this study contribute to the baseline data of carbonate parameters for the area. Tidal variability was also evident in the carbonate parameters. The lower carbonate (TA, DIC and pCO<sub>2</sub>) and high pH values obtained during spring tide are likely due to the influx of waters from outside entering the channel. During spring tide, there is a greater exchange and water mixing between mariculture water and 'cleaner' water from outside. Lower mean concentrations of nutrients and chlorophyll-a were also seen during spring tide compared to neap tide. Diurnal variability was seen in the carbonate parameters. During daytime, low TA, DIC, pCO<sub>2</sub> and high pH were observed, and during night time it was the opposite. This means that during daytime, CO<sub>2</sub> is consumed in the predominant process of photosynthesis. While during nighttime, respiration takes over releasing CO<sub>2</sub> which results in higher concentration of the carbonate parameters (DIC, pCO<sub>2</sub>) and lower pH from the formation of carbonic acid. The high AOU during night time suggests that DO is consumed by respiration.

June 5, 16:40/S3-Oral-12559

## Commercial shellfish and changing pH: will fisheries be affected by projected changes or are species already adapted?

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Experimental evidence has shown that some species will be more affected by decreasing pH, depending on their physiology and their adaptation capacity. In many areas, observations have indicated that pH levels oscillate naturally, but there is also evidence suggesting a decreasing trend in recent years. In the North Sea, detailed  $p\text{CO}_2$  projections are available up to 2100. Here, these projections have been combined with guideline historical, medium and high emissions  $p\text{CO}_2$  levels to determine the extent over which commercial shellfish may be affected. Current shell-fishing areas were overlaid with these guideline levels to determine which areas are likely to experience effects in the middle and end of the century. This was then combined with the known information on the biological effects ratios for crustaceans and molluscs, for the main UK commercial shellfish species. We show that most areas of the North Sea will experience little effect on commercial shellfish. Shell-fishing areas around the west coast of Great Britain and around Ireland are projected to experience some effects such as deformities and reduced survival, impacting shellfish production. However, stresses from other factors such as temperature and food availability may have a greater effect on shellfish survival when compared acidification. Detailed pH modelling in similar regions around the world will contribute to further understanding of shellfishery and aquaculture effects, helping to inform management measures and policy directions to increase shellfish resilience.

June 5, 17:00/S3-Oral-12658

## Model-based analyses of an ocean acidification mesocosm experiment

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Studies suggest that Ocean acidification (OA) has severe effects on marine phytoplankton. Mesocosm facilities allow investigations on impacts of OA on plankton communities in the vicinity of their natural habitats, e.g. Pelagic ecosystem  $\text{CO}_2$  enrichment (PeECE) studies. Marine ecosystem models serve as an efficient tool to analyze and interpret mesocosm data, as they use mathematical equations to describe processes controlling dynamics of planktonic ecosystems. The ultimate goal of this work is to investigate effects of OA on phytoplankton growth dynamics by analyzing data from an ocean acidification mesocosm experiment (PeECE-I) using different model approaches. To achieve this data assimilation (DA) methods are applied. These methods yield the optimized model solutions (with optimised parameter values) that maximize the likelihood probability of models explaining mesocosm data. In addition, DA methods estimate the ranges of uncertainty in optimized model parameter values. In the first study, an optimality-based model is applied to investigate the large observed variability in calcification and total alkalinity during the PeECE-I experiment. The model considers an explicit  $\text{CO}_2$  dependency of calcification. Three model experiments are set up to simulate growth of bulk phytoplankton and coccolithophores in mesocosms with high, medium and low observed calcification rates. In the second study, skills of two plankton models (OBM and CN-REcoM) that differ in their mechanistic description of nutrient uptake and algal growth are assessed against mesocosm data. It is to note that models do not resolve any  $\text{CO}_2$  effects on phytoplankton growth dynamics. The idea is to test whether this neglect of  $\text{CO}_2$  dependencies is revealed in differences of model parameter estimates between different  $\text{CO}_2$  treatments.

The model-based data analysis of the PeECE-I experiment suggests that the large variability that was observed in calcification could have been generated due to small differences in initial abundance of coccolithophores during initialization (filling) of mesocosms. Results of the second study reveal a pattern in the estimates of two physiological parameters, the potential carbon fixation rate ( $V_0$ ) and the subsistence quota ( $Q_{\min}$ ), between the  $\text{CO}_2$  treatments for the OBM. It predicts high estimates of  $V_0$  and  $Q_{\min}$  for phytoplankton in mesocosms treated with high  $\text{CO}_2$  concentrations and vice versa for those in mesocosms with low  $\text{CO}_2$ . The OBM seems to suggest that OA may enhance carbon fixation rates in phytoplankton, but at the cost of elevated metabolic stress.

June 5, 17:20/S3-Oral-12912

### **Transgenerational deleterious effects of ocean acidification on the reproductive success of a gammarid amphipod species**

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Ocean acidification (OA) poses a global threat to marine biodiversity. Notwithstanding, marine organisms may maintain their performance under future OA conditions, either through acclimation or evolutionary adaptation. Surprisingly, the transgenerational effects of high CO<sub>2</sub> exposure in crustaceans are still poorly understood. In this context, the major aim of the present study was to investigate, for the first time, the transgenerational effects (*i.e.* over two generations) of OA, from hatching to maturity, of a key amphipod species (*Gammarus locusta*). Negative transgenerational (parental) effects were observed on survival of the acidified lineage, resulting in significant declines (10-15%) compared to the control groups in each generation. Mate-guarding duration was also significantly reduced under high CO<sub>2</sub> and effects were not alleviated by transgenerational adaptation, indicating that precopulatory behaviours can be disturbed under a future high CO<sub>2</sub> scenario. Although OA may initially stimulate female investment, transgenerational exposure led to a general decline in egg number and fecundity. Overall, the present findings suggest a potential fitness reduction of natural populations of *G. locusta* in a future high CO<sub>2</sub> ocean, emphasizing the need of management tools towards species' sustainability.

June 5, 17:40/S3-Oral-13126

### **The Ocean Foundation's International Ocean Acidification Initiative: A cross-cutting program to build capacity of scientists and legislators to understand and address the complex impacts of ocean acidification**

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Though it occurs in the sea, ocean acidification's impacts stretch far onto land. From divers and deckhands who spend seven hours a day harvesting scallops in Peru, to the hotel and restaurant owners who benefit from the foot traffic brought by the scallop industry, to the massive tourism industry built on the coral-protected lagoon of Aitutaki, many communities and industries face significant threats from ocean acidification. Through its International Ocean Acidification Initiative, The Ocean Foundation (TOF) has designed training programs that help scientists and policy makers monitor, understand, and respond to ocean acidification in a way that takes into account the complexity of potential on-shore impacts. This is done through the delivery of regional capacity building workshops, development and delivery of affordable monitoring equipment, and provision of long-term financial and training support. The Initiative supports four areas: Monitoring, Analyzing, Engaging, and Acting. Through this initiative, TOF has trained over 40 scientists and 12 policy makers from ten countries in Africa and the Pacific Islands through four regional workshops, and has workshops planned in Latin America, the Caribbean, and the Arctic. A key component of the Initiative is lowering the cost of implementing monitoring programs. Together with its partners, including the Global Ocean Acidification Observing Network (GOA-ON) and the International Atomic Energy Association's Ocean Acidification International Coordination Centre, TOF created the GOA-ON in a Box kit – a set of equipment that will obtain weather quality data for the GOA-ON level 1 parameters which is 1/10<sup>th</sup> the cost of previous monitoring systems.

June 5, 18:00/S3-Oral-13023

## Projections of future oceanic biogeochemical conditions in the Gulf of St. Lawrence and on the Scotian Shelf using a coupled regional climate model

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A regional downscaling climate model was developed for the Gulf of St. Lawrence, Scotian Shelf and the Gulf of Maine. The regional circulation model is based on NEMO-OPA and the biogeochemical module includes a dissolved oxygen component as well as a dissolved inorganic carbon component. We use the results from three Earth System Models (MPI-ESM-MR, CanESM2 and HadGEM2-ES) forced with the Intergovernmental Panel on Climate Change Representative Concentration Pathways 8.5 to build future boundary conditions for nitrate, dissolved oxygen, dissolved inorganic carbon, temperature, salinity and lateral currents. The surface fields used to force the coupled model were downscaled from the Earth System Models using the Canadian Regional Climate Atmospheric Model. The atmospheric model also drives a hydrology model that provides the freshwater input of the main rivers entering the domain. Simulations were performed for the 1970 to 2100 period. The results are used to identify the regions which present the greatest changes for the different physical and biogeochemical variables as well as the greatest cumulative changes. We pay special attentions to future benthic conditions (dissolved oxygen, pH and calcium carbonate saturation states) which will likely affect the distribution and health of many fish species. Preliminaries results suggest that the bottom of the whole Gulf of St. Lawrence and part of the eastern Scotian shelf will be undersaturated with respect to aragonite by 2070.



## **S4: Deoxygenation in Global Ocean and Coastal Waters in Relation to Climate Change**

**June 6, 11:10/S4-Invited-12423**

### **Large-scale ocean oxygen changes**

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The amount of oceanic oxygen has varied on time scales of millennia to seasons. For recent decades, as well as for the future, a rather rapid change in dissolved ocean oxygen (DO) is found in observations and numerical models respectively. Subsurface low oxygen layers – oxygen minimum zones (OMZ) – exist in all ocean basins. In recent decades tropical and subtropical DO decreased in most regions of the world ocean. These DO trends are a combination of long-term trends superimposed with (multi-) decadal and short-term variability. The expansion of OMZs reduces the available habitat of pelagic fishes and affects the coastal ecosystems. Observed nutrient changes seem to be related to oxygen changes modified by local and eddy processes. An oxygen budget of available oxygen measurements revealed a world ocean oxygen loss of about 2% over the last 50 years. While the exact processes at play remain elusive, causes of the oxygen variability involve climate-change related ocean warming, variations in the supply paths of oxygen-rich water via zonal current bands, changes in the expansion and speed of the subtropical gyres, and climate related signals like the Pacific Decadal Oscillation. On the large scale the observational results are consistent with model results which predict a further oxygen decline in the future. However, causes of discrepancies on local scales between observed and modelled oxygen changes are still unresolved. By the end of the century a further decrease in the total ocean inventory of dissolved oxygen is projected which is likely caused by global warming.

**June 6, 11:40/S4-Oral-13047**

### **Ocean deoxygenation overrides ocean warming and acidification impacts in marine biota**

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Continuous CO<sub>2</sub> emissions are warming the Earth's water masses, and its oceanic uptake is leading to seawater acidification via carbonate chemistry disruption (the well-known process of ocean acidification). Concomitantly, the warming-related accentuation of natural termoclines translates into lower oxygen solubility in the upper oceanic layers. The resulting ocean deoxygenation is exacerbated by increased eutrophication and upwelling frequency of deep anoxic/hypoxic waters in coastal areas, provoking mass marine biota mortality and fisheries collapse worldwide. The aim of the present study was to investigate which of these climate change-related stressors elicit greater impacts in the marine biota, at different levels of biological organization. To estimate the such effects, we performed a meta-analysis (~900 separate experiments), divided into four categories: ocean acidification, warming, both these stressors combined, and hypoxia (deoxygenation). Although all stressors showed significant effects, an unequivocally stronger impact was found for hypoxia. This response pattern was consistent across several taxa, and at different life stages, for nearly all biotic variables measured, namely survival, abundance, metabolism, growth, reproduction and larval development. Our findings suggest that, ocean deoxygenation will be a, if not, the main deterrer of life in future oceans. Moreover, as there are theoretical basis predicting synergisms, establishing the interplay of ocean deoxygenation with warming and acidification is key to fully understand climate change impacts on marine life and socio-economical activities.

**June 6, 12:00/S4-Oral-12926**

## **Implications of ocean deoxygenation for deep-sea demersal fish communities and fisheries**

Natalya D. **Gallo**<sup>1</sup>, James P. Barry<sup>2</sup>, Rasmus Swailethorp<sup>1,3</sup>, Maryanne Beckwith<sup>1</sup>, Kevin Hardy<sup>4</sup> and Lisa Levin<sup>1</sup>

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Climate change is leading to ocean-wide losses in oxygen, with observed rates of decrease frequently surpassing modeled projections. To predict future impacts of deoxygenation we evaluated how current oxygen regimes influence the density, diversity, composition, and trophic ecology of marine demersal fishes. Oxygen minimum zone spatial and vertical oxygen gradients in the E. Pacific and Gulf of California were employed as natural laboratories where fish were studied with trawls and ROVs. Fish diversity rapidly declines below a certain oxygen threshold, with thresholds differing for different ocean regions. Fish density exhibits a lower threshold response to oxygen, with temperature and productivity having a greater influence on overall density trends. Community composition of demersal fishes changes along gradients of declining oxygen as intolerant species are excluded, accompanied by trophic changes which include: enriched  $\delta^{15}\text{N}$  signatures, suggesting higher trophic position, a reduced trophic niche breadth for the fish community, a shift from more specialist to more generalist diets, and reduced reliance on pelagic food sources. Hypoxia-tolerant demersal fish species such as catsharks and cusk-eels can live in chronic suboxic conditions ( $<5 \mu\text{M}$ ) in the Gulf of California, suggesting a possible habitat expansion for these species under climate change. While fish are unlikely to be excluded from most marine habitats, ocean deoxygenation will reduce demersal fish diversity on continental margins, lead to habitat loss for many fisheries species, and alter density, composition, and trophic structure. Autonomous landers can be a powerful tool for monitoring demersal fish responses to short- and long-term oxygen changes.

**June 6, 12:20/S4-Invited-13080**

## **Causes and impacts of ocean deoxygenation**

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Sinking and decay of surface-derived primary production coupled with long residence times naturally lowers oxygen and increases carbon dioxide in subsurface waters. General ocean circulation results in heterogeneous distributions of low subsurface oxygen. For example the Pacific has on average lower oxygen than the Atlantic. Similarly vigorous western boundary currents have higher oxygen than their eastern boundary counterparts. These general patterns result in so-called oxygen minimum zones with characteristic ecosystem dynamics. In coastal regions increased anthropogenic supply of nutrients have enhanced sinking and decay of surface-derived primary production leading to lower coastal subsurface oxygen. Here I review the general processes of modern lower subsurface oxygen in the ocean with emphasis on eastern boundary currents. Then discuss the impacts of this lower oxygen on ecosystems, goods and services.

**June 6, 14:00/S4-Oral-12721**

**Synthesis of a decade of moored time-series observations of hypoxia and ocean acidification in the northern California Current Ecosystem**

Simone [Alin](#)<sup>1</sup>, Richard Feely<sup>1</sup>, Samantha Siedlecki<sup>2</sup>, Beth Curry<sup>3</sup>, Brendan Carter<sup>1,3</sup>, Jan Newton<sup>3</sup>, Jenny Waddell<sup>4</sup> and Kathy Hough<sup>4</sup>

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Since 2006, Olympic Coast National Marine Sanctuary (Washington) has deployed bottom-mounted moorings throughout the sanctuary to monitor hypoxic events. Hypoxia forms on the shelf when phytoplankton blooms spurred by summer upwelling senesce, sink, and decay, thereby depleting bottom-water oxygen. We used time series from two mooring sites with the most complete oxygen, temperature, and salinity data from 2006 to 2017 to reconstruct aragonite saturation state ( $\Omega_{\text{arag}}$ ) through empirical relationships developed based on high-quality shipboard measurements, using oxygen and temperature as proxies for carbonate system parameters. We compared the relative frequency and duration of corrosive ( $\Omega_{\text{arag}} < 1.0$ ) and hypoxic ( $\text{O}_2 < 62 \mu\text{mol/kg}$ ) conditions at locations near the northern and southern OCNMS boundaries. We saw substantial differences in the frequency and duration of hypoxic vs. corrosive conditions across sites and years, although corrosive conditions were more frequent than hypoxia at both locations. Hypoxic and corrosive events are substantially more frequent at the southern end of OCNMS than the northern area, and also show a notable seasonal progression toward increasingly hypoxic, corrosive conditions through the upwelling season. Regional anthropogenic carbon estimates allow us to compare estimated frequency and duration of preindustrial vs. present-day corrosive events. This new analysis of ocean acidification and hypoxia dynamics will be compared to model-based estimates of the frequency and duration of hypoxic and corrosive events in a subset of years. This work will contribute to a regional vulnerability analysis of northern California Current Ecosystem organisms and the tribal communities that depend on them.

**June 6, 14:20/S4-Oral-13082**

**Changes in coastal ocean hypoxia off Oregon as influenced by multiple, climate-sensitive drivers**

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Near-bottom waters over the Oregon continental shelf in the northern California Current have become increasingly hypoxic, including the appearance of anoxia in summer 2006. Observed ecosystem impacts include the absence of fish and invertebrate die-offs. Near-bottom, inner-shelf hypoxia is driven by upwelling of low-oxygen, nutrient-rich source water onto the continental shelf, followed by the decay of organic matter from surface phytoplankton blooms. We use a variety of data sources including offshore and inner-shelf (15 m) moorings, ship-based observations, and underwater gliders to understand the spatial extent, duration and severity of hypoxia. These observations are also used to verify numerical ocean circulation and biogeochemical models of the region. Late-summer, inner-shelf hypoxia is influenced by multiple drivers, all of which are potentially influenced by climate change. These include changes in the upwelled source waters - defined as seaward of the continental shelf break on density surfaces that upwell onto the continental shelf - due to deoxygenation across the North Pacific. Given the recent declining trend in source water dissolved oxygen concentration, in 50 years the frequency of the hypoxia over the inner shelf off central Oregon is predicted to be about 90%. Another important driver is variation in the strength and persistence of local winds that, in turn, influences the amount of upwelling and the flushing rate of coastal waters. Warming surface waters can also change shelf stratification, isolating near-bottom waters from cross-shelf, wind-driven circulation. We examine how each of these drivers may influence hypoxia over the Oregon inner shelf.

**June 6, 14:40/S4-Oral-12857**

**A pause in the decline of oxygen in the largest Oxygen Minimum Zone: A response to the recent global warming hiatus?**

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Observations have shown an expansion of Oxygen-Minimum-Zone (OMZ) with a declining trend in dissolved oxygen (DO) over the past decades in the tropical Pacific in the context of global warming. Here, we employ a validated basin-scale physical-biogeochemical model to test the hypothesis that there should be a pause in the decline of DO and OMZ expansion associated with the recent global warming hiatus. Our analyses demonstrate that during the warming period prior to 2000, both oxygen supply and consumption were low in the mid-waters, but oxygen consumption exceeded supply, which led to a decline in the mid-depth DO. On the other hand, oxygen supply exceeded consumption during the warming pause (post-2000) in some parts of the basin; the strengthening of wind-driven ocean transport since around 2000 has ceased the expansion of the OMZ and has led to a pause in the decline of mid-depth DO in the tropical Pacific. The size of OMZ and DO inventory reflect a delicate balance between oxygen supply and consumption, but are more sensitive to physical supply.

**June 6, 15:00/S4-Oral-12983**

**Pacific Decadal Oscillation and recent oxygen decline in the eastern tropical Pacific Ocean**

Olaf **Duteil**, Andreas Oschlies and Claus W. Böning

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The impact of the positive and negative phases of the Pacific Decadal Oscillation (PDO) on the extension of the poorly oxygenated regions of the eastern Pacific Ocean has been assessed using a coupled ocean circulation-biogeochemical model. We show that during a “typical” PDO positive phase the volume of the suboxic regions expands by 7 % in 50 years due to a slow-down of the large scale circulation related with the decrease of the intensity of the trade winds. The oxygen levels are mostly constrained by advective processes between 10°N and 10°S while the diffusive processes are dominant poleward of 10°: in a “typical” PDO positive phase the sluggish equatorial current system provides less oxygen into the eastern equatorial part of the basin while the oxygen transport by diffusive processes significantly decreases south of 10°S. The region located north of 10°N displays less sensitivity to the phase of the PDO as the local upwelling-related processes play a dominant role compared to the large scale circulation in setting the oxygen concentration. Our study suggests that the prevailing PDO positive conditions since 1975 may explain a significant part of the current deoxygenation occurring in the eastern Pacific Ocean.

**June 6, 15:20/S4-Oral-12769**

**Study of Oxygen and Nutrients in the Arabian Sea using Model Simulations and Observations**

Chikka Kalyani **Devasena**, M. K. Sharada and P. S. Swathi

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Monitoring of the oceans using satellite remote sensing plays a major role in the global climate change studies. Since long time series observations of some of marine ecosystem variables (like Chlorophyll, primary productivity, oxygen *etc.*) are very few in the Indian Ocean, use of mathematical models along with satellite observations would help us improve our ability to understand spatial and temporal variability of the marine ecosystem at different scales. Focus of this study is on the interannual variability of oxygen in the Arabian Sea (AS) and the processes related to the oxygen minimum zone (OMZ) in the AS. This study is based on the simulations of the 0.25 deg 3-D coupled physical-biological-chemical model in the global domain. The coupled model (Modular Ocean Model-5.02 along with TOPAZ-2) is forced with climatological air-sea fluxes and integrated for 200 years and then followed by interannual fluxes using CORE (Coordinated Ocean Research Experiments) data for the period 1949-2009. The model results on nitrate, silicate and oxygen are compared with the observations from the climatological atlas on seasonal scales to ascertain the model's capability to reproduce many of the known features in the Arabian Sea. The model simulation results are also used to study the seasonal variations of primary productivity of the Arabian Sea.

**June 6, 15:40/S4-13011**

### **Reconciling systematic differences between observed and simulated ocean deoxygenation**

Andreas **Oschlies**, Wolfgang Koeve, Sunke Schmidtko and Julia Getzlaff

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The observed 2% decline of the global ocean oxygen inventory over the past 50 years is 2-3 times faster than simulated by present state-of-the-art climate models, in particular those of the fifth phase of the Climate Model Intercomparison Project (CMIP5). We investigate the global and regional model-data discrepancies and provide estimates of potential contributions from processes that are either lacking or are poorly represented in the models. New model simulations yield faster deoxygenation rates in better, but not perfect, agreement with observational estimates. Remaining uncertainties, research questions and impacts on projected future deoxygenation will be discussed.

**June 6, 16:20/S4-Oral-13070**

### **High-quality dissolved oxygen baseline for ecosystem and variability studies**

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High-quality dissolved oxygen measurements are needed to reduce the uncertainty of biological carbon fluxes, deoxygenation, and ocean ventilation variability. The World Ocean Atlas for oxygen (WOA-O<sub>2</sub>) is the most comprehensive ocean basin-scale seasonal to annual climatology available. It is based on *in situ* data from the World Ocean Database (WOD) containing the largest integrated collection of freely and publicly accessible, uniformly formatted, and quality controlled historical physical, chemical, and plankton profile data. WOA-O<sub>2</sub> is prepared using O<sub>2</sub> measurements typically obtained by Winkler chemical O<sub>2</sub> analysis of discrete samples with an uncertainty of about 1 μmol/kg. WOD also contain more recent O<sub>2</sub> data obtained by electrochemical sensors mounted on Conductivity-Temperature-Depth (CTD), gliders, Argo floats, *etc.* While some of the better sensor-based O<sub>2</sub> data are re-calibrated using O<sub>2</sub> data analyzed by Winkler titrations, most of these measurements have large uncertainties and calibration issues. In more recent years, the quantity and quality of the sensor-based O<sub>2</sub> data have significantly improved. In particular, the Argo program has increased available O<sub>2</sub> measurements through the use of profiling floats distributed throughout the ocean up to ~2000 m depth. Combining these data with O<sub>2</sub> sensor data on CTDs and gliders increases the spatial coverage of the historical data. We developed a method to check the depth-based calibration and offset calibration correction of sensor-based O<sub>2</sub> data based on profile analysis statistical methods. The quality of the augmented calibrated O<sub>2</sub> data is comparable to the WOA-O<sub>2</sub>. A description of the method will be presented along with applications.

June 6, 16:40/S4-Oral-13064

## Large oxygen decline on the northwest Atlantic Shelf from an ocean dynamical response to warming

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Global observations have shown that the ocean lost approximately 2% of its oxygen inventory over the last five decades (Helm *et al.* 2011, Schmidtko *et al.* 2017, Ito *et al.* 2017). Climate models predict this general trend will continue under future anthropogenic climate change (Keeling *et al.* 2010), with important implications for marine. In the open North Atlantic, observations and climate model projections suggest a complex pattern of change (Stendardo and Gruber 2012, Tagklis *et al.* 2017). Yet, historic observations from northwest Atlantic coastal waters have shown some of the world's most dramatic long-term drops of oxygen concentrations (Gilbert *et al.* 2010) associated with a shift toward subtropical waters (Gilbert *et al.* 2005). Here, we propose that large-scale climate forcing is driving a particularly dramatic deoxygenation of seawater on the northwest Atlantic Shelf due to a retreat of the Labrador Current. We show hydrographic evidence of this retreat in measurements collected over the 20th century, and further show the recorded changes are similar to those simulated under rising CO<sub>2</sub> in a high-resolution global coupled climate-biogeochemistry model. The model reproduces the observed decline of saturation oxygen concentrations in the region, caused by a retreat of the equatorward-flowing Labrador Current and an associated shift toward more oxygen-poor subtropical waters on the shelf. These changes are correlated with a slowdown in the Atlantic Meridional Overturning Circulation. Our results provide strong evidence that a major change of the Labrador Current is underway, and highlight the potential for ocean dynamics to play a major role in coastal deoxygenation over the coming century.

June 6, 17:00/S4-13049

## Climate-driven oceanic deoxygenation leads to an epipelagic shark 'habitat trap' more prone to overfishing

Nuno Queiroz<sup>1,2</sup>, Marisa Vedor<sup>1</sup>, Gonzalo Mucientes<sup>1</sup>, Ana Couto<sup>1</sup>, Frederic Vandepierre<sup>3</sup>, Pedro Afonso<sup>3</sup>, Rui Rosa<sup>4</sup>, Nicolas E. Humphries<sup>2</sup> and David W. Sims<sup>2,5,6</sup>

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Climate-driven expansions of permanent oxygen minimum zones (OMZs) resulting in shallower upper boundaries (shoaling) are expected to concentrate large pelagic fish further in surface waters potentially making them more vulnerable to surface fisheries. But how OMZ expansion, surface warming and fisheries may interact to impact oceanic fish populations in the future has never been quantified, which is particularly crucial for threatened pelagic sharks exposed to unregulated fishing exploitation in oceanic waters where OMZs occur. Here we show that electronic-tagged blue sharks interact horizontally and vertically with the eastern tropical Atlantic OMZ, remaining associated with the area for longer than expected, suggesting it may represent preferred foraging habitat. Maximum dive depths (MDD) of blue sharks entering the OMZ area shifted shallower compared to adjacent well-oxygenated habitats, and such MDD decrease was significantly associated with decreasing dissolved oxygen (DO) at depth and increasing sea surface temperature (SST). From this model relationship we predict further vertical habitat compression for blue shark of 30–50 m depth in the next 50 years, when we estimate sharks may encounter longline hook depths~30% more often during dives than at present. Furthermore, analysis of satellite-tracked surface longline vessels shows fishing intensity is greater directly above OMZs compared to adjacent areas. We argue that this future environmental setting will lead to a 'habitat trap' for pelagic sharks with more rapid overfishing above OMZs as a consequence of expanding hypoxia driven by climate change, and in the absence of strict fishery catch controls.

**June 6, 17:20/S4-Oral-13043**

## **Contribution of nuclear applications to study the effects of reduced oxygen in coastal environments**

Marc Metian<sup>1</sup>, Francois Oberhaensli<sup>1</sup>, Simon Pouil<sup>1</sup>, Miguel Gomez<sup>2</sup>, Murat Belveris<sup>3</sup> and Peter W. Swarzenski<sup>1</sup>

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Research on marine organisms has primarily focused on single stressors. Recently there has been a trend to broaden the scope to more complex studies; this is particularly true for global stressors such as climate-change drivers since there are many complex biogeochemical interactions involved and there still exist large uncertainties of their combined effects. Nuclear techniques allow for studying complex conditions that marine organisms will likely face in the future and constitute a complementary tool to assess potential effect of local and global threats. The use of radiotracers offers many advantages in comparison to more classical approaches. Among them, it is a unique tool to better understand the fate of contaminants on organisms in a changing environment, and can also help assess some physiological reactions to counteract such stressors. Such tools have been used for the past 3 decades to assess contamination (metals, organic compounds and radionuclides) but more recently, methodological advancement have been made to study the synergistic effects of multi-stressors on fish across varying trophic levels (from cellular to organismal).

A new stressor has been added to the portfolio of key parameters (salinity, temperature, pH and pCO<sub>2</sub>) that can be finely regulated in controlled aquaria. IAEA Monaco has now developed and tested a new technique that also regulates the dissolved oxygen content in controlled microcosm. To date, experiments to address varying levels of deoxygenation have incorporated mussels, corals, and fish species. This talk presents preliminary results from these experiments using radiotracers.

**June 6, 17:40/S4-Oral-12790**

## **Stream discharge and nutrient export from the Ohio River watershed under future climate change scenarios**

Ozeas Costa Jr.

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There is growing evidence that human-induced climate change is changing global patterns of precipitation and the hydrological cycle. Over the past twenty years, numerous studies have detected remote associations (teleconnections) between rising air temperatures and global precipitation, since a warmer climate spurs the evaporation of water from land and sea and allows the atmosphere to hold more moisture. As a result, wet places tend to get wetter and, similarly, dry places tend to get drier, increasing the risks of extreme weather events such as floods and droughts. The U.S. Midwest has experienced noticeable changes in its climate over the last several decades. From 1900-1950, temperatures have increased at a rate of 0.06°C/decade, but over the last 50 years this rate has jumped to 0.26°C/decade. Heat waves are becoming more frequent and cold periods are becoming rarer. Precipitation patterns have also changed, and the last three decades have been the wettest on record. Heavy downpours now occur twice as frequently as they did a century ago. Summer rainfall currently accounts for almost 50% of the annual total, and most of this precipitation results from small scale, regional systems. Snow and ice are arriving later in the fall and starting to melt earlier in the spring. Significant spatial and temporal variabilities have been observed throughout the region, and are described in this presentation, with focus on the Ohio River watershed.

**June 6, 18:00/S4-Oral-12827**

**The competing impacts of climate change and nutrient reductions on dissolved oxygen in Chesapeake Bay**

Isaac D. **Irby**, Marjorie A. M. Friedrichs, Fei Da and Kyle E. Hinson

Virginia Institute of Marine Science, Virginia, USA. E-mail: isaacirby@gmail.com

The Chesapeake Bay region is projected to experience changes in temperature, sea level, and precipitation as a result of climate change. This research uses an estuarine-watershed hydrodynamic- biogeochemical modeling system along with projected changes in temperature, freshwater flow, and sea level rise for a 2050 scenario to explore the impact climate change may have on future Chesapeake Bay dissolved oxygen (DO) concentrations and the potential success of nutrient reductions in attaining mandated estuarine water quality improvements. Results indicate that warming Bay waters will decrease oxygen solubility year-round, while also increasing oxygen utilization via respiration and remineralization, primarily impacting bottom oxygen in the spring. Rising sea level will increase the volume of the Bay, pushing coastal saline water further into the Bay. Changes in precipitation are projected to deliver higher winter and spring freshwater flow and nutrient loads, fueling increased primary production. Together, these multiple climate impacts will lower DO throughout the Chesapeake Bay and negatively impact progress towards meeting water quality standards associated with the Chesapeake Bay Total Maximum Daily Load. However, this research also shows that the potential impacts of climate change will be significantly smaller than improvements in DO expected in response to the required nutrient reductions, especially at the anoxic and hypoxic levels. Overall, increased temperature exhibits the strongest control on the change in future DO concentrations, primarily due to decreased solubility, while sea level rise is expected to exert a small positive impact and increased winter river flow is anticipated to exert a small negative impact.



## **S5: Climate change impacts on high latitude systems on multiple scales in space and time**

**June 4, 11:35/S5-Invited-13253**

### **Ecosystem Response to Antarctic Climate Variability and Change**

Grace **Saba**

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Antarctic ecosystems undergo large natural variability on multiple scales. Furthermore, long-term datasets have revealed that certain regions in Antarctica, including the West Antarctic Peninsula (WAP), are currently seeing rapid rates of change in atmospheric temperature, glaciers and ice sheets, sea ice extent and concentration, and precipitation patterns. Concurrently, there are predictions that the Southern Ocean will be impacted by ocean acidification. As the life histories of residing organisms are attuned to ice seasonality, recent trends in the WAP and elsewhere are associated with changes at key trophic levels in both pelagic and benthic food webs. Due to the stochastic nature of the system, however, linking these changes unequivocally to anthropogenic factors is difficult and will require longer time series measurements but nonetheless highlights the importance of these model systems for monitoring and observing impacts of rapid change. What is evident from ecological research conducted thus far is that adaptation to climate change is contingent on the plasticity of organism responses, and the ability for populations to relocate to regions of more suitable habitats. This presentation will cover current environmental trends occurring in different regions in Antarctica, and will summarize responses of residing species encompassing multiple trophic levels in Antarctic food webs.

**June 4, 12:05/S5-Oral-13234**

### **The interaction of climate conditions and spatial overlap structure condition and recruitment success of Walleye pollock in the eastern Bering Sea**

Elizabeth **Siddon**<sup>1</sup>, Tayler Jarvis<sup>1</sup>, Kirstin Holsman<sup>2</sup> and Alex Andrews<sup>1</sup>

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Mechanistic understanding of early life history and recruitment dynamics in marine fishes increases our ability to project cohort strength under future climate scenarios. In the eastern Bering Sea, annual differences in sea ice dynamics and oceanographic conditions affect the quantity and quality of prey resources that subsequently impact growth, fitness, and survival of young fish (e.g., Walleye pollock, *Gadus chalcogrammus*). Utilizing empirical observations between 2003-2016, indices of spatial overlap between juvenile pollock and (i) foraging landscapes and (ii) predator abundances were developed. Spatially explicit bioenergetic modeling was also used, including local predator and prey condition, to estimate growth potential spatially and temporally over the shelf. The index of prey overlap indicates years of higher overlap between lipid-rich prey and juvenile pollock lead to greater recruitment success while the index of predator overlap shows that predation pressure is more strongly and positively correlated with recruitment in cold years. Juvenile pollock experience lower growth rates in warm years compared to conspecifics in colder conditions and growth 'hot spots' indicate differential growth conditions across the shelf. Combined, these analyses provide refinement to the current understanding of ecosystem response and highlight the importance of spatial patterns in both prey and predators. This work also demonstrates the relative contributions of bottom-up and top-down processes to help explain recruitment variability across climate stanzas in the eastern Bering Sea.

**June 4, 12:25/S5-Oral-12989**

## **Feedbacks between wintertime sea ice and summertime heat content and phytoplankton bloom strength in a 20-year Antarctic time series**

Hugh **Venables**<sup>1</sup>, Michael Meredith<sup>1</sup>, J. Alexander Brearley<sup>1</sup>, Oliver Legge<sup>2</sup> and Patrick Rozema<sup>3</sup>

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<sup>3</sup> Univeristy of Groningen, Netherlands

During the twenty years of the Rothera Time Series (RaTS), year-round physical and biological sampling has been carried out near Rothera, the British Antarctic Survey base on the west Antarctic Peninsula. Considerable variability in sea ice duration in the region, with the regional minimum around 2008, is reflected in local conditions. Low sea ice in winter leads to deep wind-driven mixing, releasing heat and carbon to the atmosphere. The following summers are characterised by reduced stratification in the top 100m, preconditioning the system to a greater extent of vertical mixing. This leads to deeper penetration of surface warming, such that between 50m and 100m these years see both the coldest and warmest temperatures in the time series. This increases the heat content in autumn, despite the wintertime cooling, giving a positive feedback effect on reduced sea ice duration. The phytoplankton bloom also decreases by approximately an order of magnitude, with a reduced proportion of large diatoms present. This is despite continual ice melt leading to very shallow mixed layer depths. Ocean gliders have shown that vertical overflows at sills in the glacially carved bathymetry propagate these temperature changes to 400m and deeper on seasonal to decadal timescales. Overall, the variability gives a unique window into the shifts that might occur in the region under prolonged sea ice changes. It should be noted that atmosphere-sea ice-ocean feedbacks are extremely numerous and the dominant processes can be very sensitive to local and regional conditions and could change over time.

**June 4, 14:00/S5-Oral-13021**

## **Primary drivers of changes in productivity in a future warmer Barents Sea**

Erik A. **Mousing**<sup>1,2</sup>, Anne Britt Sandø<sup>1,2</sup>, Philip Wallhead<sup>3</sup>, Solfrid S. Hjøllø<sup>1,2</sup>, Ingrid Ellingsen<sup>4</sup> and Morten D. Skogen<sup>1,2</sup>

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Inflow of warm and saline water into the Barents Sea and fluxes between the ocean and the atmosphere are of significant importance to the regional climate and ecosystem productivity. Regionally downscaled physical models with high spatial resolution and a good representation of the heat flux are thus essential to predict future changes in productivity and ecosystem structure. Here we compare future changes in productivity following climate change as predicted by three ecosystem models (NORWECOM, NORWECOM.E2E and SINMOD) driven by three regionally downscaled ocean circulation models. The predicted production differs between the models and ranges from a modest decrease to a large increase. We use correlative modeling to deduce the primary environmental variables responsible for the predicted changes. Preliminary results suggest that future changes in productivity in all models are primarily correlated to changes in temperature, ice-cover and light which works directly or indirectly by modifying nutrient and mixed layer dynamics. Thus, the discrepancy between model predictions is to a large extent caused by the choice of the underlying physical forcing. Using output from the NORWECOM model we further demonstrate that as the temporal scale decreases, wind induced turbulent mixing in the upper ocean layers becomes increasingly important for explaining changes in productivity, probably due to increased introduction of nutrients from below the pycnocline. Last, we show how single events affecting the heat influx into the Barents Sea can have a lasting impact on productivity in the entire Barents Sea, effectively resetting the state of the ecosystem and masking general trends.

June 4, 14:20/S5-Oral-13088

## Climate change impacts in the NE Atlantic transition zone between the Subarctic and Arctic

Ken **Drinkwater**<sup>1</sup>, Randi Ingvaldsen<sup>1</sup>, Benjamin Planque<sup>2</sup>, Melissa Cherici<sup>2</sup>, Jan Erik Stiansen<sup>1</sup>, Arne Eide<sup>3</sup> and Alf Håkon Hoel<sup>2</sup>

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<sup>3</sup> University of Tromsø, Tromsø, Norway

In this presentation, we synthesize the present knowledge on the anticipated future climate changes and the resultant ecological responses in the Northeast Atlantic Ocean with emphasis on the transition zones between the Arctic and Subarctic regions. This includes the Barents, the northern Norwegian, and the Greenland seas as well as Fram Strait and the Atlantic sector of the Arctic. Higher temperatures, lower salinities, less sea ice and higher acidity are anticipated. This is expected to result in more primary production over intermediate (decadal) time scales although at longer (centennial) time scales increased stratification may reduce primary production but this is highly uncertain. Zooplankton abundance is expected to increase where primary production increases although the abundance of larger copepods will likely decrease with higher temperatures. The mean zooplankton size will decrease. There is expected to be an expansion northward of many zooplankton and fish species as temperatures rise. Higher recruitment with subsequent increases in abundance of cod, herring and haddock, especially in the Barents Sea, are likely. Adult fish should not be greatly affected directly by ocean acidification but may be influenced through effects on their prey. Fish eggs and early larval stages might be more sensitive owing to their high surface-to-volume ratios and less developed acid-base regulation systems. Finally, we will speculate on which, if any species, are likely to make it into the Arctic.

June 4, 14:40/S5-Oral-12587

## Continuous and abrupt changes in the resilience of northeast Atlantic marine ecosystems

Marcos **Llope**<sup>1,2</sup>, Thorsten Blenckner<sup>3</sup>, Paraskevas Vasilakopoulos<sup>4,5</sup>, Niall McGinty<sup>6</sup>, Christopher P. Lynam<sup>7</sup>, Pierre Helaouët<sup>8</sup>, Joël Durant<sup>1</sup>, Leif C. Stige<sup>1</sup>, Guðrún Marteinsdóttir<sup>9</sup> and Nils Chr. Stenseth<sup>1</sup>

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Changes in climate in addition to anthropogenic factors, such as fishing, largely affect the dynamics of marine ecosystems. The last five decades were characterised by some of the highest fishing pressures and warming rates ever observed, in particular in the high latitudes. In order to better understand the future impacts of climate change it is important to know how these ecosystems have responded to stressors in the past. In this study, we analyse the long-term dynamics and the resilience of four northeast Atlantic ecosystems: the Icelandic Seas, the Barents Sea, the North Sea and the Baltic Sea. This is done holistically by applying an Integrated Resilience Assessment (IRA) framework, which involves: (i) a multivariate analysis of multiple trophic levels to analyse system indicator variables, (ii) non-additive modelling to estimate alternate attractors, and (iii) a quantitative resilience assessment to estimate the stability of these ecosystems to multiple drivers. The particular geographical setting here addressed comprises temperate and Arctic (south-north) environments as well as open and semi-enclosed (southeast-northwest) topographies. Some of these ecosystems were found to have evolved in a more or less linear fashion, while others showed drastic changes. By comparing our results along these climate and multiple driver gradients we discuss the implications of connectivity and diversity in the observed patterns and trajectories.

**June 4, 15:00/S5-Oral-12999**

### **Climate change impact on Barents Sea ecosystem functioning and vulnerability**

Raul **Primicerio**<sup>1</sup>, Michaela Aschan<sup>1</sup>, Magnus Aune<sup>2</sup>, Marie-Anne Blanchet<sup>1</sup>, Padmini Dalpadado<sup>3</sup>, Andrey Dolgov<sup>4</sup>, Elena Eriksen<sup>3</sup>, Maria Fossheim<sup>3</sup>, Andre Fraimer<sup>1</sup>, Lis Lindal Jørgensen<sup>3</sup>, Susanne Kortsch<sup>1</sup>, Ulf Lindstrøm<sup>3</sup>, Mette Skern-Mauritzen<sup>3</sup>, Paul Renaud<sup>2</sup> and Øystein Varpe<sup>2</sup>

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The Barents Sea ecosystem is undergoing rapid structural change driven by climate warming. Ecosystem alterations are particularly extensive in Arctic waters, where poleward distributional shifts of demersal and pelagic fish species bring about changes in species composition and community structure. The restructuring of Arctic marine communities modifies food web configurations and functional characterization, with implications for ecosystem functioning and vulnerability. We address climate-driven changes in ecosystem properties affecting ecosystem functioning and vulnerability, relying on trait-based methods and food web analyses applied to the Barents Sea Ecosystem Survey Data collected by the Institute of Marine Research (Norway) and PINRO (Russia). We find that, in Arctic waters, functional characterization is changing towards an increased importance of larger, more generalist pelagic feeders. These changes in functional characterization, associated with increased seawater temperature and reduced ice coverage, are accompanied by food web reconfigurations leading to increased connectance and decreased modularity. The observed changes affect ecosystem functioning, by *e.g.* modifying the degree of benthic-pelagic coupling. Ecosystem vulnerability is also being affected, with three of its main components, functional diversity and redundancy, and food web modularity, all displaying rapid and extensive change in Arctic waters. The documented changes in functional characterization and food web configuration, driven by climate warming, will lead to substantial alterations in the ecosystem functioning and vulnerability of this Arctic marine ecosystem.

**June 4, 15:20/S5-Oral-13045/**

### **Diverse responses to warming in the Barents Sea**

Elena Eriksen, Mette **Skern-Mauritzen** and H. R. Skjoldal

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The Working Group for Integrated Ecosystem Assessment for the Barents Sea (WGIBAR) is a multidisciplinary group of scientists, seeking to describe the ecosystem state and to understand underlying processes causing changes in the ecosystem. The Barents Sea climate has changed much during the last five decades from a cold climate condition with much sea ice in the period 1960-1980, to record warm temperature conditions with loss of half of area with winter ice during 2000s. The recent warming has significantly impacted the productivity and the structure of the ecosystem, with increased net primary production and increased production of meso- and macroplankton. These conditions in turn have secured favorable environmental conditions for recruitment and growth of boreal fish stocks, increasing and expanding in the system, while arctic species are declining and contracting. The northeast Atlantic cod stock, the prime predator in the system in terms of consumption, is among the expanding boreal species, changing the top-down impacts on forage fish, partly resulting in a last capelin stock collapse. Other top predators, including seals and seabirds, are negatively impacted by recent developments, possibly associated with both loss of habitat and resource competition with cod. While the increasing productivity of the system seem to buffer against some of the recent changes, the restructuring of the system is expected to increase system vulnerability to further impacts through increased connectivity between food web compartments (*e.g.*, boreal and arctic compartments, and pelagic and benthic compartments), allowing for responses to perturb through larger parts of the system.

**June 4, 15:40/S5-Oral-13160**

### **Biophysical response of the Bering Sea to projected global climate of the 21<sup>st</sup> century**

Albert **Hermann**<sup>1</sup>, Wei Cheng<sup>1</sup>, Georgina A. Gibson<sup>2</sup>, Ivonne Ortiz<sup>1</sup> and Kerim Aydin<sup>3</sup>

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Using a regional biophysical oceanographic model with 10 km horizontal resolution, we have dynamically downscaled twelve projections of global climate from CMIP3/CMIP5 to investigate their impact on the regional physics and biology of the Bering Sea. The regional model includes ice and tidal dynamics, water column nutrient-phytoplankton-zooplankton dynamics, benthos, and ice plankton. Our forcing ensemble includes both medium (rcp4.5) and high (rcp8.5) emission scenarios (scenario uncertainty), as well as global model realizations from GFDL, CESM and MIROC centers (model uncertainty). Results demonstrate likely future changes in the extent and shape of the “cold pool” on the continental shelf, as well as changes to the spatial patterns of primary and secondary production. A substantial retreat of the cold pool and significant declines in large crustacean zooplankton are projected, particularly after 2040, and especially under high emission scenarios. We explore the gradual shift in likelihood distributions (*e.g.* the shifting probabilities of extremely warm/cold and productive/unproductive years), from the present through 2100.

**June 4, 16:00/S5-Oral-12350**

### **Climate change effects on the linkages between environmental factors, zooplankton and pelagic fish in the Norwegian Sea**

Lísa Anne **Libungan**, Hildur Pétursdóttir, Guðmundur J. Óskarsson and Ástþór Gíslason

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The ability to predict how animals will react in a changing ocean, for example due to climate change, relies on our understanding of the interaction of fundamental players in the ecosystem and their physical adaptations to environmental factors. The Norwegian Sea is characterized by dramatic conditions, where cold and low saline polar currents from the north meet warm and saline currents from the south. The Marine and Freshwater Research Institute in Iceland has monitored the oceanic region east of Iceland in detail for the past decades with regards to hydrography, zooplankton and pelagic fish. Here, we focus on two oceanic sub-regions east of Iceland over a 22 year period (1995-2017) where the sea temperature was higher during the latter half of the period. We attempt to answer the following questions: (1) Has the species composition, abundance and development of zooplankton changed over the past 22 years (1995-2017)? (2) Are there interactions between environmental factors, development and abundance of zooplankton and the abundance and migration pattern of herring? (3) Does the composition and abundance of zooplankton in the ocean reflect the food items which herring prey on? The results of this study will provide a novel understanding on the linkages between the migration behavior and feeding ecology of herring and the zooplankton community structure. Increased knowledge on zooplankton, which play a vital role in marine food webs and their interactions with the environment and inhabiting pelagic fish stocks, is fundamental to predict changes in the marine ecosystem by using ecosystem models.

**June 4, 16:40/S5-Oral-13107**

### **Distribution of plankton and pelagic fish in a future climate**

Kjell Rong Utne<sup>1</sup>, Solfrid S. Hjøllø<sup>1,2</sup>, Morten D. Skogen<sup>1,2</sup>, Erik A. Mousing<sup>1,2</sup>, Cecilie Hansen Eide<sup>1</sup> and Espen Strand<sup>1</sup>

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The abundance, spatial distribution and recruitment of pelagic fish in the Nordic Seas are driven by a range of factors, but at least three are important; water temperature, prey availability and stock biomass. Taking the future ocean climate (temperature/hydrography, velocity, turbulence *etc.*) from simulations with the climate model NORESM forced with RC4.5 IPCC climate scenario and downscaled with Regional Ocean Modelling System (ROMS) to sufficient regional resolution, we have simulated future fish population adaptation to changes in physics and food availability using the ecosystem model NORWECOM.E2E. NORWECOM.E2E is a fully coupled model system consisting of the ocean model ROMS, a NPZD model for nutrient cycling and lower trophic levels, and several individual based modules for large zooplankton and pelagic fish. The three main processes movement, growth & feeding and mortality, is explicitly modelled for each individual and then aggregated to population levels. Due to lack of information on how migration patterns will change with future climate change, present day migration patterns were used and future migration algorithms tested. Preliminary results from the simulations show that the water temperature change in the northeast Atlantic has local spatial differences, but will generally increase. The production of *Calanus finmarchicus* is increased and found more north and west in the region. Thus the abundance of pelagic fish will in general increase, but the change in abundance differ between the respective species. The distribution envelope is dependent on the seasonal migration patterns applied.

**June 4, 17:00/S5-Oral-13108**

### **Biomass fluctuations of Eastern Bering Sea jellyfish: Recent trends and environmental drivers**

Mary Beth Decker<sup>1</sup>, Richard Brodeur<sup>2</sup>, Lorenzo Ciannelli<sup>3</sup>, Robert R. Lauth<sup>4</sup>, Nicholas Bond<sup>5</sup>, Bart Difiore<sup>6</sup> and George L. Hunt, Jr.<sup>7</sup>

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A steep substantial increase in jellyfish biomass was documented over the eastern Bering Sea shelf throughout the 1990s. Their biomass peaked in summer 2000 and then declined precipitously, stabilizing at a moderate level during 2001-2008. From 2009-2011, biomass increased to late-1990s levels, but declined starting in 2012, and levels in 2016 and 2017 were quite low. Previous investigations of a 27-year time series examined relationships between jellyfish biomass and temperature, ice cover, atmospheric variables, current patterns, zooplankton biomass, and associated fish biomass in two regions using Generalized Additive Models (GAM). These analyses indicated that jellyfish outbreaks during 1982-2004 were influenced regionally by interacting variables such as sea ice cover, sea surface temperature, currents, wind mixing and food availability. Using updated environmental data from 2009-2017, with the exception of zooplankton biomass which was unavailable for this period, we reran our models to determine if our previous models would predict recent trends in jellyfish. GAMs predicting jellyfish biomass for the period 1982-2017 explained a large fraction of the variance for the southeast and northwest portions of the survey area, respectively, using strictly physical variables and the lag biomass from the preceding year. Peaks in zooplankton biomass during the time series precede increases in jellyfish biomass, suggesting that food availability is an important factor contributing to fluctuations in jellyfish populations. Models that use more readily available physical parameters are needed for predicting jellyfish abundance and their potential impacts on commercially important species.

**June 4, 17:20/S5-Oral-12719**

**Geographical distribution of the alien snow crab (*Chionoecetes opilio*) as a response to increased warming in the Barents Sea**

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Climate change and temperature increase are commonly linked to species extinction and shifts in species range. Temperature increase has led to a borealization of arctic fish communities in the Barents Sea, and may also affect sedentary species in the area. Within the recent two decades the abundance of the alien snow crab has increased rapidly, and the crab has become a significant feature of the Barents Sea ecosystem. The effects of this new species on the Barents Sea ecosystem is unknown. However, any potential effect will vary dependent on how widely distributed the crab will be once the Barents Sea is fully colonized. The snow crab is known to prefer sea temperatures between – 1.5 and 4°C. Based on these preferences and on information on bottom temperature regimes we have estimated the future distribution of the crab in the Barents Sea under scenarios of one and two degrees temperature increase. The results indicate significant decrease in potential bottom areas being affected by the crab as temperature increase.

**June 4, 17:40/S5-Oral-12683**

**Fish distributions and climate variation in the northern Bering Sea: A comparison of two bottom trawl surveys**

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The climate regime in the eastern Bering Sea has recently been dominated by a pattern of multi-year stanzas, in which several years of relatively extensive sea ice formation and cold summer temperatures are followed by several successive years of minimal sea ice formation and warm summer temperatures. The NMFS Alaska Fisheries Science Center recently conducted two bottom trawl surveys covering the entire Bering Sea continental shelf, from the Alaska Peninsula to the Bering Strait. The first, in the summer of 2010, was conducted during a cold year, when the majority of the continental shelf was covered by a pool of cold (<2°C) water. The second, in the summer of 2017, was during a warmer year, with water temperatures slightly above the long-term survey mean. These two surveys recorded significantly different spatial distributions for populations of several commercially important fish species, including Walleye Pollock and Pacific Cod, particularly in the northern portion of the survey area. Interannual population shifts included latitudinal displacement as well as onshore-offshore movements and alterations in recruitment dynamics. These large-scale distributional shifts in high-biomass species raise questions about long-term ecosystem impacts, and highlight the need for continued monitoring. They also raise questions about our management strategies for these and other species in Alaska's large marine ecosystems.

**June 4, 18:00/S5-Oral-12938**

**A regional assessment of projected impacts of climate change on Arctic fish and fisheries under scenario, process, and structural uncertainty**

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Climate change impacts on Arctic ecosystems are projected to occur sooner with amplified severity relative to other regions of the planet. However, the information available to quantitatively project these impacts on marine fish and shellfish resources differs regionally with the information being most limited at high latitudes. This paper contrasts the projection capabilities in the information rich regions of the Barents and Bering Seas with those of three high Arctic coastal regions (Chukchi, Beaufort, and Kara Seas). In data-rich regions, integrated multi-model approaches can be used to explore the relative contributions of scenario, process, and structural uncertainty when assessing future impacts of climate change on fish and fisheries. For example in the Bering Sea, analysts downscaled ocean conditions in the Bering Sea using scenarios from three global models under two representative concentration pathways (RCP 4.5 and 8.5) and explored the implications of projected ocean conditions on the productivity of 5 groundfish species under different management strategies. In higher latitude systems, although some output from earth system models is available, the gaps in knowledge of the processes underlying fish production limit the ability to fully explore the implications of alternative harvest strategies for fish and shellfish. We propose an information-based, tiered risk assessment which could serve as a framework for management of Arctic marine fish and shellfish resources.



## S6: The deep ocean under climate change

June 4, 11:35/S6-Invited-12531

### Climate-human-policy connections in deep-ocean ecosystems

Lisa Levin

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The deep ocean (>200 m) plays a large role in climate mitigation, removing heat and CO<sub>2</sub> from the atmosphere in ways that alter the temperature, circulation, dissolved oxygen, carbonate system, and food supply in deep waters. The consequences for deep-sea ecosystems will include redistribution and habitat compression of species with commercial value or trophic significance, loss of habitat and support values via effects on foundation species, changes in biodiversity, and altered food web structure. These changes will intersect with physical, chemical and biological disturbance imposed by increasingly deeper extraction of living, energy and mineral resources. Continental margins, seamounts, canyons and potentially nodule-covered abyssal plains may be most affected. Climate stress interacting with human disturbance may act to reduce ecosystem resilience, alter times and trajectories for recovery from disturbance, or impose new (non-analog) conditions. Environmental management of deep-ocean ecosystems now requires an ecosystem-based framework that incorporates climate change into spatial planning and conservation (including MPA design), baseline observation and monitoring, and environmental impact assessment. Climate considerations relevant to international instruments (SDG 13 & 14, FAO RFMO, the ISA, UNFCCC, BBNJ) require new observational data to inform climate projections in deep water as well as biogeochemical, species and ecosystem responses and feedbacks. International networks focused on deep-ocean observation (Deep Ocean Observing Strategy – DOOS), conservation (Deep-Ocean Stewardship Initiative – DOSI), and basic research (International Network for scientific investigation of DEEP-sea ecosystems – INDEEP) offer unprecedented potential to link deep-sea climate science to societal needs in the deep half of the planet.

June 4, 12:05/S6-Oral-12562

### Utility of habitat suitability modelling tools for evaluating changes in VME distribution under future climate scenarios

Telmo Morato<sup>1</sup>, Carlos Dominguez-Carrió<sup>1</sup>, Andrew Davies<sup>2</sup>, Marina Carreiro-Silva<sup>1</sup>, Andrew Sweetman<sup>3</sup> and Chih-Lin Wei<sup>4</sup>

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Future climatic scenarios predict changes in some environmental properties in the deep sea, which have been shown to exert a strong influence on growth and survivorship of deep-sea coral species under mesocosm experiments. Making use of presence data from the Ocean Biodiversity Information System (OBIS) and a set of projections for POC flux, dissolved oxygen, seawater pH and potential temperature at seafloor in the year 2100, we modelled the habitat suitability for 6 cold-water coral species under current and future climate conditions using Maxent, for two Regional Fisheries Management Organisation (RFMO) areas in the northern Atlantic Ocean. All species but *Madrepora oculata* showed a reduction in the extension of their predicted distribution area in 2100. Terrain variables had the highest predictive contribution in most models, but POC flux and dissolved oxygen concentration were also important variables structuring the distribution of many species. In this talk, we will discuss the utility of habitat suitability modelling for evaluating changes in VME distribution under future climate scenarios; in particular the suitability of existing environmental and biological data, the fact that global climate projections may not capture localised effects most important for deep-sea benthic organisms, and the usefulness of such models for management purposes.

**June 4, 12:25/S6-Invited-12707**

**Deep-sea ecosystems in a changing ocean and the importance of basin-scale research for their long-term management and conservation**

Murray **Roberts**

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We stand poised at a unique point in time. It is clear that anthropogenic climate change has altered and will continue to alter global biogeochemical cycles for generations to come. It is clear that these effects will cascade through ecosystems in complex and often unpredictable ways. However, we are also at a point in human history when developments in observational and biological technologies along with unprecedented social connectivity give us new opportunities to observe the natural world and communicate our findings to widest possible audiences. The last two decades have seen major leaps in deep-sea technological capacity across scientific disciplines. For the physicists, emerging technologies include mixed arrays of moored instrumentation and ocean gliders capable of observing physical parameters of ocean currents and overturning circulation at greatly improved spatial and temporal scales. For biologists and ecologists the possibilities opened by access to remote and robotic survey and sampling allied with next generation sequencing technologies will revolutionise our understanding of deep-sea ecosystem functioning and connectivity. As the largest single habitable space on Earth the deep ocean transcends national boundaries. Scientific, legal, governance and policy developments for the deep ocean all require well integrated and aligned international partnerships. A key next step in our development of deep-sea management must be to work effectively at ocean basin scale. This talk will explore the challenges and opportunities of basin scale research using the Atlantic as a case study. From 2016-20 the ATLAS project brings together 25 partners from Europe, Canada and the USA to complete a transatlantic assessment and deep-water ecosystem based spatial management plan ([www.eu-atlas.org](http://www.eu-atlas.org)).

**June 4, 14:00/S6-Oral-12703**

**Future trends in seafloor community biomass in a global, body size-resolved model**

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Deep water benthic communities are an important source of seafood, are highly biodiverse, and mediate long-term carbon burial in seafloor sediments. However, they are ultimately almost wholly dependent on near-surface pelagic ecosystems for their supply of energy and material resources. This supply is the residual flux of particulate organic carbon (POC) reaching the seafloor after the majority is recycled through complex pelagic food webs. Advances in understanding have shown the importance in these communities of size-structuring of organisms. In recognition of this, the body size-based BORIS model has been developed and parameterised using seafloor data from disparate 3 sites. Here we apply BORIS at global scale using output from a pelagic ecosystem model, MEDUSA, for both present-day and future conditions. Simulations find diverse seasonal behaviour in response to food supply with temporal variability decreasing and lagging increasing as organism size increases. A key finding is the dominant role of the magnitude of organic carbon supply to the seafloor. As MEDUSA projects benthic food supply decreasing into the future, particularly so at depth, benthic communities may be seriously impacted. These results highlight, in particular, the importance of reducing uncertainty in seafloor POC flux, both for the present-day and in the factors that may drive it in the future.

**June 4, 14:20/S6-Oral-12871**

### **Vulnerability of deep-sea fishes to climate change**

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Vulnerability and risk of impact of marine species to climate change (including ocean acidification) depend on species' ecological and biological characteristics, as well as their exposure to climate hazards. Most existing assessments focus on coastal species but systematic analysis of climate vulnerability for the deep-sea is lacking. Here, we apply analytical algorithms that combine fuzzy logic expert system with species distribution modelling to assess the risks of climate and fishing impacts to the population viability of 41 species of exploited deep-sea fishes across the global ocean. All species will experience high and very high exposure to climate hazards, as characterized by warming, deoxygenation, acidification and changes in precipitated organic carbon relative to historical variability in deep-sea habitats, by mid and end of the 21<sup>st</sup> century, respectively, under 'business-as-usual'. Deep sea fishes that are predicted to be most vulnerable to climate change include antarctic toothfish (*Dissostichus mawsoni*), yellowtail flounder (*Limanda ferruginea*) and golden redfish (*Sebastes norvegicus*). Their high vulnerability is a result of their large body size and narrow thermal tolerance, rendering them particularly sensitive to changes in ocean conditions. Spatially, high concentration of vulnerable deep-sea species is predicted in the northern Atlantic Ocean and the Indo-Pacific region while areas with high risk of impacts were predicted in the offshore West Africa and South Pacific regions. The findings suggest that deep-sea species are as vulnerable to climate change as coastal species; therefore, deep-sea species should be routinely included in national and regional climate vulnerability assessment.

**June 4, 14:40/S6-Oral-12706**

### **Using a trait-based vulnerability assessment to estimate sensitivity and adaptive capacity of vulnerable marine ecosystems to climate change**

Marina **Carreiro-Silva**<sup>1</sup>, Nadine Le Bris<sup>2</sup>, Ana Colaço<sup>1</sup>, Lisa Levin<sup>3</sup> and Joana R. Xavier<sup>4</sup>

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Understanding and measuring vulnerability of species, habitats, and ecosystems to climate change is a major scientific challenge. In the deep ocean, vulnerable marine ecosystems (VMEs) are increasingly at risk from combined stresses of warming, ocean acidification, deoxygenation, and altered food inputs. Such changes can significantly affect deep-sea organisms' physiology, life history traits (e.g. growth and reproduction) and recruitment, with concomitant changes in biodiversity and provisioning of goods and services by deep-sea ecosystems. As currently defined, VMEs encompass a wide range of ecosystems such as cold-water coral reefs/gardens, sponge grounds/reefs, and chemosynthetic vents and seeps, defined by a number of intrinsic and functional characteristics. Here we use a trait-based vulnerability assessment approach (TVA) to estimate the sensitivity and adaptive capacity of VME-indicator species (i.e. corals, sponges, vents and seeps bivalves/decapods/polychaetes) to climate change. The approach measures three dimensions of climate change vulnerability, namely sensitivity, exposure and adaptive capacity. Through this approach we identify the main traits that define VMEs vulnerability to climate change, as well as the main knowledge gaps that still exist on the biology and ecology of such ecosystems which prevents us to fully understand the impacts that climate change may pose upon them. Based on examples from terrestrial and marine coastal ecosystems, species' traits will change little over assessment timeframes, while exposure estimates, which depend on human actions and model predictions, will be more frequently updated. Therefore we propose that TVAs can be useful tools as indices of change and for recommending adaptive management strategies for deep-sea ecosystems.

**June 4, 15:00/S6-Oral-12977**

**Deep water flow in the channel between east and west Mariana basins**

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Mooring and hydrography observations were conducted in the channel between East and West Mariana Basins. Moored current meters on the east side of the channel revealed southeastward flow during August 2014-October 2015, and southwestward flow during November 2015- November 2016. The LADCP deep velocity section across the channel in November 2016 showed northward transport on the west side and nearly zero transport on the east side. Mooring measurement of deep ocean temperature and current further showed significantly intensified fluctuations near the bottom. The intensification can also be seen in the vertical profiles of turbulent dissipation rate. We interpret such bottom intensified fluctuation as topographic Rossby waves (TRWs) with period of about 32 days. The bottom-trapped TRWs had a vertical trapping scale larger than 1000 m, and horizontal wavelength of about 110 km. The direction of TRWs' group velocity was northwest, suggesting that the generation of TRWs was related to the seamount to the southeast of the mooring. The amplitude of TRWs increased when two energetic cyclonic eddies passed by the mooring site, which suggests that the generation of TRWs may be associated with upper ocean eddies.

**June 4, 15:20/S6-Oral-12978**

**New seafloor *in situ* laboratories based on fixed and mobile robotic platforms to monitor indicators of deep-sea ecosystem functioning and address their vulnerability to industrial activities and climate change**

Nadine **Le Bris**<sup>1</sup>, Dimitri Kalenitchenko<sup>2</sup>, Erwan Peru<sup>1</sup>, Jacopo Aguzzi<sup>3</sup> and Laurenz Thomsen<sup>4</sup>

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In the recent decades, the development of fixed observatories has shed light on short-term environmental variability at the ocean floor, in relation to resource pulses or hydrodynamic forcing. Any ecological impact assessment in the deep-sea, in the context of industrial activities or climate change, should address potential synergies among stressors accounting for such natural climate-sensitive instabilities. In this context, however, our capacity to monitor functional responses of ecosystems at great depth is still critical.

Opportunities raised by newly available sensing technologies enable to downscale these observations and fill gaps in our understanding of how the environmental dynamics interplay with key ecosystem functions. Here, we present the result of pilot experiments in different deep-sea hotspots (*e.g.* submarine canyons, cold seeps or hydrothermal vents) showing how cost-effective modular macro and micro-observing platforms enable to document the interaction of fauna with transient biogeochemical processes in their habitat. Moreover, we show how fluid and adaptive networks of fixed and mobile robotic platforms can be used to expand our monitoring capability over larger and complex geomorphologies, providing at the same time those tools required for direct manipulation capability in perturbations experiments (*e.g.* simulating maritime industrial activities in terms of photic contamination, noise, and sediment resuspension).

Such *in situ* microscale observations are to be developed in any habitat targeted for protection and conservation (*e.g.* MPA, VME, or areas considered for EIA) especially where down-welling and upwelling phenomena, massive organic inputs, geophysical instabilities such as volcanic eruptions as well as industrial impacts, act as key factors driving the dynamics of deep-sea communities and the functions they hold.

**June 4, 15:40/S6-Oral-12849**

### **The deep ocean biodiversity under climate change: Integrative research and adaptive governance towards ocean and climate resilience**

Bleuenn **Guilloux**<sup>1</sup>, Sören Thomsen<sup>2</sup>, Françoise Gaill<sup>3</sup>, Nadine Le Bris<sup>4</sup>, Julien Rochette<sup>5</sup> and Jörn Schmidt<sup>6</sup>

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Although the ecological interdependence among the ocean and the climate as part of the complex Earth system is scientifically accepted, the impacts of climate change on the deep ocean biodiversity remain poorly addressed by ocean governance. We highlight how marine biodiversity and climate related issues such as deoxygenation, warming and acidification are considered in the ongoing UN process towards an international agreement on the sustainable use and conservation of marine biodiversity in areas beyond the limits of national jurisdiction (BBNJ). This analysis reveals gaps between scientific approaches and political action based on scientific findings, which could be reduced through integrative research and subsequent adaptive governance. By integrative research, we mean breaking down the barriers between scientific disciplines, policy and society. It should support the development of an adaptive governance approaches and mechanisms such as area management tools, especially marine protected areas, environmental impact assessments, capacity building and technology transfer. Such governance co-evolves with advances in fundamental knowledge, Research & Development progresses and evolving natural and human (socio-economical) environment. Thus, integrative research for adaptive governance is needed to allow ocean biodiversity and climate resilience.

**June 4, 16:00/S6-Oral-13009**

### **Measuring progress on ocean and climate initiatives: An action-oriented report**

Loreley **Picourt**<sup>1</sup>, Victor Brun<sup>1</sup>, Claire de Courcy-Ireland<sup>1</sup> and Françoise Gaill<sup>2</sup>

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The oneness of ocean and climate is the fundament in which we exist. Yet, climate change is having major impacts on the ocean, its ecosystems and coastal populations. It is therefore necessary to address the realities of ocean change and to consider the ocean as a source of adaptation and mitigation solutions.

The report “Measuring Progress on Ocean and Climate Initiatives: An Action-Oriented Report” of the Ocean and Climate Initiatives Alliance (OCIA) presents international and multi-stakeholder partnerships aiming to accelerate the objectives of the Paris Agreement. The study provides an analysis of 13 initiatives across seven themes, including ocean acidification and marine ecosystem resilience. For instance, the ‘Deep-Ocean Climate Mitigation and Adaptation’ initiative, launched by DOSI and DOOS, brings together deep-sea scientists across disciplines to raise awareness about the importance of the deep ocean for climate mitigation and adaptation, by strengthening and coordinating observation of the deep ocean. The deep sea (>200m below the surface) represents over 98% of the ocean in volume and proportionally contributes to climate regulation and providing marine biodiversity habitats.

OCIA aims at ensuring effective multilateral cooperation for deep ocean protection in the international fora, notably by disseminating scientific knowledge and providing complementarity between policy and science. Identifying communities of multi-actors is necessary to integrate the deep sea in international processes, especially with regards to deep-sea resources and finding alternative energy solutions.

## **S7: Eastern Boundary upwelling systems: Diversity, coupled dynamics and sensitivity to climate change**

**June 7, 11:10/S7-Invited-12759**

### **Land-sea-atmosphere interactions exacerbating ocean deoxygenation**

Véronique **Garçon**<sup>1</sup>, Boris Dewitte<sup>1,2,3,4</sup>, Ivonne Montes<sup>5</sup> and Katerina Goubanova<sup>2</sup>

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While the biogeochemical and physical changes associated with ocean warming, deoxygenation and acidification occur all over the world ocean, the imprint of these multiple stressors has a strong regional and local nature such as in the Eastern Boundary Upwelling Systems (EBUS). EBUS are key regions for the climate system due to the complex of oceanic and atmospheric processes connecting to the open ocean, troposphere and land, and to the fact that they shelter Oxygen Minimum Zones (OMZs), responsible for the world's largest fraction of water column denitrification and for the largest estimated emission of the greenhouse gas N<sub>2</sub>O. While there is no doubt that ocean deoxygenation is an ongoing process, there is still a critical gap of knowledge in understanding the driving mechanisms, the extent, the spatial and temporal variability of ocean deoxygenation as well as of its impact on marine food webs and biogeochemistry. Understanding how land-air-sea interactions control the dynamics behind the OMZs and may potentially exacerbate deoxygenation becomes not just a matter of scientific interest, but also a major societal concern. We provide here a brief synthesis of current research focused on the intricate interactions between the ocean, atmosphere and land in the EBUS by emphasizing the processes driving these interactions, their time-scales modulations, their impacts on oxygen depletion and on future rates of deoxygenation within a changing climate. Land-air-sea interactions partly regulating the EBUS-OMZs dynamics certainly deserve more investigation since they continue to be an area of high uncertainty in understanding the Earth system.

**June 7, 11:40/S7-Oral-13105**

### **Effect of environmental fluctuation amplitude on community temporal structure**

Lucie **Buttay**<sup>1</sup>, David A. Vasseur<sup>2</sup>, Antonio Bode<sup>3</sup>, Manuel Varela<sup>3</sup>, Enrique Nogueira<sup>4</sup> and Rafael González-Quirós<sup>1</sup>

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Upwelling systems at Eastern Boundary Currents are among the most productive areas around the globe but changes in the frequency and strength of upwelling events are expected as a consequence of global warming. One of the characteristics that has been highlighted to have strong consequences for the stability of ecological communities is their temporal structure. As such, we examined the effect of environmental fluctuations (amplitude) on community temporal structure by combining empirical observations and theoretical simulations. Observations consisted in monthly data of phytoplankton composition sampled, from 1994 to 2009, in the Galician coast which correspond to the northern part of the Canary upwelling system. A wavelet analysis of the species series and upwelling intensity series allowed to follow how their characteristics (*i.e.* amplitude and phase) varied through time. We identified a sudden increase of the synchrony among diatom species from 1998 to 2002, concomitant with an increase in the amplitude of upwelling intensity at different scales. To better understand the underlying mechanisms that relate the nutrient fluctuations with the inter-specific synchrony we simulated, with a chemostat type model, the dynamic of two species with fixed stoichiometric requirements competing for essential resources (*e.g.* nitrate, silicate). Environmental variability has been simulated by adding fluctuations in one of the resources' inflow. Our results revealed that, for all the stoichiometric ratio that allowed stable coexistence of both competitors, an increase in resource fluctuation amplitude lead to more synchrony. This relationship is however not linear and we hypothesized that inter-specific competition can buffer the effect of increasing amplitude until a certain threshold at which environmental fluctuation becomes the main driver of community temporal structure.

June 7, 12:00/S7-12568

### Coastal variability and change in the Benguela Upwelling system: Decadal trend analysis

Folly Serge **Tomety**<sup>1,2</sup>, Mathieu Rouault<sup>1,2</sup> and Serena Illig<sup>1,3</sup>

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Sea Surface Temperature is a good indicator to monitor upwelling strength in Eastern Boundary Current such as the Benguela Current. Satellite remote sensing allows estimating sea surface temperature for most of the ocean since the 1980's. Over the last 35 years, the ocean has warmed globally but some regions are showing a cooling. Detecting trend in coastal upwelling is challenging due to proximity of the coast and clouds. A rigorous analysis of sea surface temperature observations of various data sets over 35 years is used to examine variability and seasonal temperature trends in the Angola, Benguela and Agulhas current systems using four different datasets (Reynolds SST 1°×1° resolution, Reynolds SST 0.25°×0.25°, Hadley SST 1°×1°, Pathfinder 4×4 km). Significant annual warming trend were found off of the Angola and Namibian coast (>0.35°C per decade) and in the Agulhas retroflection region in all dataset and cooling trend is found in the Southern Benguela and South Coast of South Africa where a strong seasonally depend wind driven upwelling occurs. However, cooling or warming trends are seasonally dependent. Warming trend is more pronounced in early austral summer off the Angola and Namibia coasts and in late summer in the Agulhas Current retroflection region in all datasets. However, in the Benguela upwelling system (BUS), notable differences in SST trends among the datasets occur. Some data indicate a significant cooling trend up to 0.5°C in the Southern Benguela upwelling especially in autumn and early winter while other datasets indicate little change.

June 7, 12:20/S7-Oral-13198

### Climate, anchovy and sardine in the California Current: A mechanistic understanding

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An end-to-end model was analyzed to explore the impact of climate variability on recruitment dynamics of anchovy and sardine in the California Current System. ROMS-NEMURO hydrodynamic-biogeochemical models provided the variable physical (water velocities, temperature) and prey fields (zooplankton) as inputs for an individual-based full life cycle model configured for the two small pelagic fish species. Model analysis was designed to explore how spatiotemporal changes in key abiotic (circulation, temperature) and biotic (zooplankton) conditions could influence their distribution, growth and survival, especially during El Niño Southern Oscillation (ENSO) events and among documented regime shifts over 1965-2000. Our results indicated that spatial changes in the environment determined, to a considerable extent, the spawning and rearing habitats of anchovy and sardine. Warmer conditions during El Niño years and multidecadal regimes induced a northward shift in the distribution of eggs and recruits. Spatial match-mismatch dynamics of eggs with optimal development temperature and larvae with their prey, in combination with their southward dispersal, were key processes to regulate egg and larval survival, and ultimately define spatial patterns of recruitment. The differences in anchovy and sardine early life dynamics between warmer El Niño and colder La Niña years illustrated the benefit of end-to-end modeling approach to infer how these stocks may respond under future climate events. Finally, this study exhibited the distinct responses of anchovy and sardine to environmental forcing owing to their differences in life history and habitat characteristics (*i.e.*, nearshore/offshore distribution, feeding preferences, behavioral movement).

June 7, 14:00/S7-Oral-12852

## **Role of Interannual Kelvin waves propagations in the equatorial Atlantic on the Angola Benguela current system**

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The link between equatorial Atlantic Ocean variability and the coastal region of Angola-Namibia is investigated at interannual time scales from 1998 to 2012. An index of equatorial Kelvin wave activity is defined based on Prediction and Research Moored Array in the Tropical Atlantic (PIRATA). Along the equator, results show a significant correlation between interannual PIRATA monthly dynamic height anomalies, altimetric monthly Sea Surface Height (SSHA), and SSHA calculated with an Ocean Linear Model. This allows us to interpret PIRATA records in terms of equatorial Kelvin waves. Estimated phase speed of eastward propagations from PIRATA equatorial moorings remains in agreement with the linear theory, emphasizing the dominance of the second baroclinic mode. Systematic analysis of all the strong interannual equatorial SSHA shows that they precede by 1-2 months extreme interannual Sea Surface Temperature Anomalies along the African coast, which confirms the hypothesis that major warm and cold events in the Angola-Benguela current system are remotely forced by ocean atmosphere interactions in the equatorial Atlantic. Wind anomalies in the Western equatorial Atlantic force equatorial downwelling and upwelling Kelvin waves that propagate eastward along the equator and then poleward along the African coast triggering extreme warm and cold events, respectively. A proxy index based on linear ocean dynamics appears to be significantly more correlated with coastal variability than an index based on wind variability. Results show a seasonal phasing, with significantly higher correlations between our equatorial index and coastal SSTA in October-April.

June 7, 14:20/S7-Oral-12548

## **Origin and pathways of the central water masses in the Benguela Upwelling system and the impact of the Agulhas leakage**

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We analysed the origin and age of intermediate waters that well up in the Benguela Upwelling System (BUS) located off southwest Africa, one of the four large Eastern Boundary Upwelling Systems (EBUS). EBUS's very high primary production is supported by upwelling of cold sub-thermocline and nutrient-rich water masses in response to trade-wind induced offshore Ekman transport. Upwelling in the BUS is fed by two distinct central water masses that cause differences in the nutrient, CO<sub>2</sub> and oxygen states of the northern and southern sub-systems, and the relative predominance of these water masses has significant effects on the ecosystem. We analyse a simulation with an ocean model INALT20 (GEOMAR, Germany), a global ocean simulation with the 1/4 degree and a nested 1/20 degree resolution over the South Atlantic and Indian Ocean, for the time period 1958-2009. Our focus lies on the impact of the Agulhas Leakage on the South Atlantic water masses at intermediate depths. To investigate the pathways and ages of the two upwelling water masses before they reach the Namibian shelf, we used the Lagrange software ARIANE for tracking water parcel trajectories in the ocean simulation. Both intermediate water masses contain Agulhas Leakage water and differ in transport history and age. As a second part, the Agulhas Leakage response to wind stress variations was analysed. The position and intensity of the westerly belt and the easterly trades north of it appear to modulate the amount of water of the Agulhas Current reaching the South Atlantic.



June 7, 14:40/S7-Oral-12465

### Using available fishery, ecological and environmental time series to examine temporal variability in the Southern Benguela ecosystem over the past four decades

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A revised, updated and re-fitted trophic model of the Southern Benguela is developed to capture recent advancements in our understanding of dynamics and changes in the ecosystem, its ecological components and the environment. For the period 1978/9-2015, a temporally-dynamic *Ecosim* food web model was fitted to catch and species abundance data; ecosystem dynamics were driven in the model by newly available upwelling indices, and fishing effort. The most sensitive predator-prey interactions were identified and vulnerabilities (of prey to predators) were estimated to improve model fit to data series of field observations; bottom-up flow control of sardine by phytoplankton, and of seabirds, cetaceans and shallow-water Cape hake by sardine was observed, whereas top-down flow control of zooplankton by sardine and chub mackerel, and of sardine by yellowtail and Sciaenids emerged in the fitting process. Model fits to data were improved when production of small phytoplankton was varied, while upwelling effects on microzooplankton availability to zooplankton and small pelagic fish was incorporated. This work shows promise in unravelling the observed dynamics of the Benguela upwelling ecosystem. Improving our understanding of the processes whereby variability in upwelling influences the dynamics of the Southern Benguela ecosystem is important in reconciling the knowledge needed to manage fisheries and to protect marine biodiversity by means of ecosystem-based management in South Africa, and to advance management under future scenarios of climate change.

June 7, 15:00/S7-Oral-12577

### Oceanic resolution controls differences between fast-SST-error-growth in CCSM4 simulations of the subtropical Southeastern Pacific

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Coupled climate models are stymied by tropical SST errors. One path forward to understanding the model causes for the error is to assess the error growth within the first week, before remote influences confuse the attribution. Improvements in the spatial grid spacings, in both the oceanic and atmospheric domains, are also thought to lead to improved simulations. This idea is tested in this study using hindcast simulations based on the Community Climate System Model (CCSM4) at two resolutions, with the parameterizations otherwise left unchanged. The hindcasts were initialized on January 1 with the real-time oceanic and atmospheric reanalysis (CFSR) from 1982 to 2003, forming a 10-member ensemble. The two resolutions are (0.1° oceanic and 0.5° atmospheric) for the high-resolution and (1.125° oceanic and 0.9° atmospheric) for the low-resolution. The SST error growth in the first six days of integration (fast errors) are assessed and compared towards evaluating the model processes responsible for the SST error growth. The models were found to differ the most in their depiction of the southeastern Pacific fast SST-error growth. For the high-resolution simulation, SST fast errors are negative (-0.5°C) near the continental borders and positive offshore (+0.3°C). In contrast, the low-resolution simulation manifested positive SST fast errors over most of the study area, reaching +1.5°C near the coast. The atmospheric fast error correlations with SST were similar, indicating an oceanic source for the difference. Differences will be further explored, and time permitted, a similar analysis extended to the southeast Atlantic.

June 7, 15:20/S7-Oral-13074

## **Dynamical relationship between the equatorial circulation and OMZ in the Eastern Tropical South Pacific between 1990 and 2008: A high-resolution modeling approach**

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The Eastern Tropical South Pacific (ETSP) hosts one of the most extended Oxygen Minimum zones which are mainly maintained by a combination of sluggish circulation and high biological productivity in the surface layer leading to elevated organic matter decomposition consuming dissolved oxygen. These low-oxygen areas are important not only for marine macroorganisms that cannot survive in oxygen-poor conditions, but also because of special biogeochemical processes occurring at low oxygen concentrations. In particular, the ETSP OMZ is strongly modulated by the remote variability exerted by the equatorial dynamics (*i.e.*, circulation, El Niño), owing its proximity to the equator, and by the local variability exerted by coastal upwelling driven by the divergence in Ekman transport. Here we use a high-resolution physical-biogeochemical model of the oxygen minimum zone off Peru to investigate the O<sub>2</sub> budget and its drivers at a variety of timescales, from intraseasonal to interannual. Our focus is on processes modulating the OMZ volume and the effect of the interaction between timescales on the O<sub>2</sub> changes near the coast and the role of mesoscale activity. Implication of our results for understanding the low-frequency variability of the OMZ off Peru is discussed.

June 7, 15:40/S7-Oral-13071

## **Evaluating the use of a high-resolution Earth System Model in the Humboldt Current ecosystem to understand regional large-scale climate variability**

Kristin Kleisner<sup>1</sup>, Vincent **Saba**<sup>2</sup>, Emanuele Di Lorenzo<sup>3</sup>, Merrick Burden<sup>1</sup>, Erica Cunningham<sup>1</sup>, Dimitri Gutierrez<sup>4</sup>, Jorge Tam<sup>4</sup>, Mauricio Galvez<sup>5</sup>, Carolina Hernandez<sup>5</sup> and Fernando Espindola<sup>5</sup>

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The Humboldt Current eastern boundary upwelling system (EBUS) is recognized as one of the most productive ecosystems in the world. The biomass of primary producers in this region fluctuates over intra- and interannual time scales in response to environmental variability, and especially to changes in the magnitude of upwelling, which has strong effects on upper trophic levels. In particular, the strong upwelling in this region supports some of the world's largest fisheries, including the Peruvian anchoveta, a species of great social and economic importance in the region. Many of these fisheries are driven by large-scale climate variability such as the Pacific Decadal Oscillation and the El Niño Southern Oscillation (ENSO). Climate change is expected to increase the intensity and/or frequency of strong El Niño events and create changes in the species composition of the region as species change distribution patterns across the region. Sophisticated climate and oceanographic models have been used to try to understand and forecast the oceanographic effects of changes in temperature, wind patterns, and productivity on the Humboldt Current ecosystem. Our work proposes to build on this body of work by using a new high-resolution (0.1° ocean resolution) Earth System Model, which better resolves key features like regional wind stress, which is critical for capturing productivity patterns, and which may be useful for understanding fluctuations in higher trophic level species like anchoveta. We use satellite-derived data as well as regional observations to understand the influence of large-scale climate variability on the upwelling regimes in the Humboldt Current.

**June 7, 16:20/S7-Oral-13191**

### **Changes in the Peruvian upwelling system under future climate scenarios**

Manon **Gévaudan**<sup>1,2</sup>, Francois Colas<sup>1</sup>, Vincent Echevin<sup>1</sup>, Dante Espinoza-Morriberón<sup>1,2</sup>, Jorge Tam<sup>2</sup> and Dimitri Gutierrez<sup>2</sup>

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There is a great uncertainty about the impact of future climate change on the high biological productivity in the Peruvian coastal sea. It depends on a subtle interplay between changes in coastal winds, oceanic circulation and subsurface nutrients concentration. An approach to tackle these questions is to perform dynamical downscaling of global IPCC models : coarse resolution solutions are used to force a high resolution (~10 km) regional ocean model ROMS, coupled to the biogeochemical model PISCES. This regional model is known to reproduce realistically physical and biogeochemical processes that are essential to the system functioning.

The RCP 8.5 (pessimistic) scenario is downscaled over the period 2000-2100 for three CMIP5 models: IPSL-CM5A-MR, GFDL-ESM2M and CNRM-CM5. A special focus is given on the end of the century (2090-2100). Results indicate an ubiquitous, significant warming in the coastal area that is attributed to the strong increase in ocean stratification rather than coastal wind changes. A decrease in subsurface nitrate content, combined to a slight reduction of coastal upwelling, lead to a reduction of the productivity. Further changes in nutrients, oxygen and plankton biomass are discussed in the light of seasonal cycle analysis and simulations comparison.

**June 7, 16:40/S7-Oral-13211**

### **Modeling climate change impacts on California Current System oceanography and fisheries**

Elizabeth **Drenkard**<sup>1,2</sup>, Arthur Miller<sup>1</sup> and Sam McClatchie<sup>2</sup>

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Global climate change may have profound impacts on the California Current System (CCS) and its lucrative US-west coast fishing industry. However, the minimum resolution necessary to resolve processes that will drive changes in fish distributions and thereby affect fisheries is currently unknown. Here we use a 4km Regional Ocean Modeling System (ROMS) model of the CCS to study changes in mean-state parameters such as temperature, circulation and water mass proportions, and to infer possible implications for CCS fisheries. The reference model is forced with recent (1981-2010) climatological ocean (SODA) and atmospheric (ERA interim) conditions, three end-of-century (2081-2100) model runs are additionally forced with climatological ocean and atmospheric anomalies derived from the NCAR Community Earth System Model (CESM), Large Ensemble Community Project (LENS). In order to capture the range of future CCS variability, we use three LENS end members exhibiting the warmest, average, and coldest mean California coastal SST under Representative Concentration Pathway 8.5. In addition to comparing our historical and future model runs, we will discuss the skill with which 30-year averaged forcing fields reproduce present day CCS structure, as well as how end-of-century ROMS scenarios compare with coarser global model simulations.

**June 7, 17:00/S7-Oral-12773**

### **A water mass history of the Southern California Current System**

Steven **Bograd**<sup>1,2</sup>, Isaac D. Schroeder<sup>1,2</sup>, Michael Jacox<sup>1,2</sup> and Elliott Hazen<sup>1,2</sup>

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Historical hydrographic data (1950-2016) from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program were used to quantify the water mass history off southern California. Recent observations have shown declining dissolved oxygen concentrations within the lower pycnocline, concurrent with increases in nitrate and phosphate that have spatial patterns matching those of dissolved oxygen. Silicic acid also shows an increasing trend in the offshore portion of the region, but has strong and opposing trends in the upper (increasing) and lower-pycnocline (decreasing). The varying rates of change in the inorganic nutrients yield a more complex pattern of variability in the nutrient ratios, resulting in large decreases in the N:P and Si:N ratios at depths that provide source waters for upwelling. Here we extend these observations back to the 1950s, using optimum multiparameter analysis to diagnose source waters and quantify cross-shore water mass structure from the coastal zone to the transitional areas within the southern California Current System over decadal time scales. The observed variability in regional biogeochemistry reflects variations in the advection of modified source waters, and may have important ecosystem impacts including a reduction of viable pelagic habitat and community reorganization.

**June 7, 17:20/S7-Oral-12929**

### **Biogeochemical drivers of hypoxia in a coupled bio-physical model of the California Current Ecosystem**

Raphael **Dussin**<sup>1</sup>, Enrique Curchitser<sup>1</sup>, Charles Stock<sup>2</sup> and Nicolas Van Oostende<sup>3</sup>

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Recent observations have shown an increase of the hypoxic area on the shelf in the California upwelling ecosystem. Climate projections suggest this increase would continue over the 21st century. Unfortunately, the low-resolution ocean component of today's climate models in this region are hampered by an inadequate representation of upwelling and coastal processes. Using a high resolution regional coupled bio-physical model, permitting a seamless representation from global to coastal scales, we performed a suite of downscaled sensitivity experiments for projected future changes in biogeochemical and physical drivers of coastal hypoxia. Perturbations on dissolved oxygen and nutrients content in the upwelling source waters are shown to have greater impact than more regional effects, such as increase of ocean temperature alone and upwelling-favorable atmospheric circulation. These results emphasize the critical role of large scale ocean deoxygenation on the coastal hypoxia

**June 7, 17:40/S7-Oral-12743**

### **Interannual to decadal variability of biogeochemical conditions along the British Columbia continental shelf and slope**

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The British Columbia shelf is at the northern end of the California Current System and is influenced by summer coastal upwelling, mesoscale eddies, and freshwater inputs. Previous studies have shown significant interannual to decadal variability in primary production, nutrient fluxes and subsurface oxygen concentration related to oceanographic conditions. A regional coupled circulation-biogeochemical (ROMS-NPZD) model of this region has been developed to gain a better understanding of the variability of the region. In particular, model results are examined to identify the potential mechanisms driving changes in inshore-offshore nutrient fluxes, primary production and subsurface oxygen concentrations. These variations are discussed within the context of climate change.

June 7, 18:00/S7-Oral-12838

## Physical and biogeochemical controls on dissolved oxygen in coastal upwelling systems

João H. **Bettencourt**<sup>1</sup>, Vincent Rossi<sup>2</sup>, Lionel Renault<sup>1</sup>, Peter Haynes<sup>3</sup>, Yves Morel<sup>1</sup> and Véronique Garçon<sup>1</sup>

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Coastal and shelf regions are particularly vulnerable to deoxygenation due to the highly productive upper ocean ecosystem and to physical transport bringing low oxygen levels from subsurface open ocean waters. Here we use a coupled physical-biogeochemical model of an idealized coastal upwelling system of the Iberian Peninsula to determine the factors controlling dissolved oxygen variability. An Oxygen-Phytoplankton-Zooplankton model is implemented within the ROMS model and the system is forced by upwelling favourable wind stress. It causes the surfacing of cold, nutrient-rich waters promoting phytoplankton growth and oxygen production by photosynthesis. An unstable front generates a field of mesoscale and submesoscale turbulence that controls the stirring of the oxygen field and redistributes dissolved oxygen across the shelf. A bi-modal pattern emerges with oxygenated waters inshore and depleted waters offshore, although small-scale turbulence tends to homogenize this gradient by transporting offshore oxygen-rich submesoscale filaments. Oxygen enrichment of the surface coastal upwelling is highly sensitive to wind regime and phytoplankton growth rate. Our model results suggest that sustained upwelling lowers the enrichment rate due to continuous low oxygen injection from below; conversely, a wind relaxation period following intense upwelling increases the enrichment rate due to the cessation of low oxygen input, allowing photosynthesis to replenish the oxygen levels. Changes in the phytoplankton growth rate substantially reduce the rates of oxygen enrichment due to strong non-linear interactions between biological and physical factors. Future work will aim at disentangling those complex processes driving oxygen concentrations variability in a more permanent and less oxygenated upwelling system.

## **S8: Understanding the impact of Abrupt Ocean Warming and Continental Scale Connections on marine productivity and food security via Western Boundary Currents**

**June 4, 16:20/S8-Oral-12753**

### **Summary of an FAO workshop regarding the effects of climate variability and change on short-lived species and their forecasting with a focus on squid stocks and Boundary Currents**

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Recent studies have documented strong changes in intensity and position of global Boundary Currents, including the Kuroshio and Agulhas Currents, which are shifting poleward. Cephalopods are reacting to these changes and several studies suggest that some commercially important squids and other cephalopods may be benefiting from changes in the ocean environment. Methods for predicting and forecasting abundance, spatial distribution, recruitment and phenology, while accounting for environmental variability, would benefit fishery managers and fishermen. The Food and Agriculture Organization of the United Nations (FAO) sponsored a three-day workshop in November 2017 that brought together 22 squid and oceanography experts from around the world. The objective was to review progress on assessing and forecasting the effects of climate variability and change on short-lived species. Emphasis was placed on squid stocks because of their short lifespan, generally less than one year, and the close relationship between their population dynamics and environmental variability. Ommastrephid squids were focused on because their early life history stages are closely linked to Boundary Currents. We will highlight outcomes from the workshop and present a general framework to advance forecasting capabilities for short-lived squid species in support of fisheries management.

**June 4, 16:40/S8-Oral-12895**

### **Climate change effects on the early recruitment of largehead hairtail (*Trichiurus japonicus*) in the East China Sea**

Peng **Sun**, Jianchao Li, Wenjia Li and Yongjun Tian

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Largehead hairtail (*Trichiurus japonicus*) is a commercially-important fish species in China Seas, characterized by wide distribution, large migration, long spawning period and high economic values. The East China Sea is one of the typical over-exploited ecosystems in the world where most of the fish populations are under overfishing including largehead hairtail. In spite of the long-term increasing fishing pressure, however, the catch of largehead hairtail showed obvious increasing trend in recent years, particularly the catch proportion of immature fishes has been on the rise since the 1990s with increasing water temperature. In this study, with focus on the changes in the characteristics in the early life history of largehead hairtail, we explore the relationship between the growth traits of juveniles and the environment in Zhoushan fishing ground, which is an important habitat and spawning ground for largehead hairtail. Meanwhile, as one of oceanic factors significantly affected by climate change in the East China Sea, summer upwelling provides rich prey for juvenile of largehead hairtail, therefore, remote sensing and simulated data were combined to obtain the ocean and climate features along with the upwelling intensity in the East China Sea. Results show that the Kuroshio Current and the upwelling system in the East China Sea are generally strengthened after 1990 under the background of climate change in spring and summer, which lead to the improvement of primary productivity in Zhoushan area and contribute to success in the early recruitment of largehead hairtail. Our results have important implications for the fishery management and sustainable utilization of largehead hairtail in the over-exploited China Seas.

June 4, 17:00/S8-Oral-12969

### Effects of climate change on growth and distribution of Japanese anchovy (*Engraulis japonicus*) larvae in the East China Sea

Shin-ichi **Ito**<sup>1</sup>, Takashi Setou<sup>2</sup>, Toru Hasegawa<sup>3</sup>, Satoshi Kitajima<sup>3</sup>, Akinori Takasuka<sup>2</sup>, Naoki Yoshie<sup>4</sup>, Takeshi Okunishi<sup>5</sup>, Motomitsu Takahashi<sup>3</sup>, Micho Yoneda<sup>6</sup>, Yuuhei Amano<sup>7</sup> and Chenying Guo<sup>1</sup>

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We have evaluated climate change (global warming) effects on Japanese anchovy (*Engraulis japonicus*) larvae in the East China Sea by integrating a fish-migration and growth model using environmental conditions derived from simulations of a coupled ocean circulation and ecosystem model with contemporary and future climate forcing. For the ocean circulation model, a high resolution (1/10 deg.) FRA-ROMS (Fisheries Research Agency - Regional Ocean Modeling System) was used. For the marine ecosystem model, eNEMURO, an extended version of NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) was used. For contemporary and future climate forcing, the output of MRI-CGCM3 with the Representative Concentration Pathways (RCP) scenarios (RCP2.6, RCP6.0 and RCP8.5) were averaged during 2011-2020, 2051-2060 and 2091-2100, the FRA-ROMS-eNEMURO was integrated with those climatological forcing for 26 years and the simulated results in the last year were used to integrate the fish-migration and growth model (FRA-ROMS-eNEMURO.FISH). The initial spawning grounds were estimated based on the sea surface temperature (SST) and day length with limitation of ocean depth less than 1000 m. The spawning grounds shifted to northward under warming conditions however because of day length limitation, the available eggs decreased by the northward shift. The larvae transported to southern part of Kyushu Island in Japan (current main fisheries ground for anchovy larvae) were projected to decrease under warming conditions and the peak timing of larvae supply was shifted earlier. The projected results indicate severe conditions of local fisheries in the southern part of Kyushu Island.

June 4, 17:20/S8-Oral-12867

### Climate-induced variations in the sea surface temperature in subtropical Kuroshio waters and its effect on Pacific saury

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Pacific saury (*Cololabis saira*), an important small pelagic fish for Asian-Pacific countries, is widely distributed in Northeastern Pacific and makes large-scale migration from their spawning ground in subtropical Kuroshio waters south of Japan to the feeding ground in Oyashio waters east of Japan. The catch of Pacific saury is affected not only by the environmental conditions in the fishing ground, but also by the recruitment process related to environmental conditions in the spawning ground. In this study, we focus on the effect of the latter, particularly in relation to the position and size of the spawning ground, represented by sea surface temperature (SST) 19°C contour line and the area of SST 18-22°C zone, respectively. We associated climatic indices, including Southern Oscillation Index (SOI) and Asian Monsoon Index (MOI), and SST in the spawning ground with the catch of Pacific saury during 1950 to 2011 to detect the response of saury to the decadal climate change. In the spawning ground, both SOI and MOI were negatively correlated with SST, suggesting that climate-induced variations in SST can alter the position and size of spawning ground; the abundance of large-size Pacific saury was positive correlated with SST. Both the position and size of the spawning ground and catch of Pacific saury showed the same decadal variation patterns as climate change in 1976/77 and 1988/89. Based on our analysis, we infer that the impacts of variations in climatic indices and SST on the catch of Pacific saury may have been attributed to the alteration of marine physicochemical properties and current conditions in the spawning ground, which has affected the food availability in the early life stages of Pacific saury and subsequently recruitment.

June 4, 17:40/S8-Oral-12880

### Regime shifts in the fish assemblages around Japan over the last century and their early warning signals

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The marine ecosystems around Japan, one of the most productive regions in the North Pacific, are under the impact of the warm Tsushima and Kuroshio currents and the cold Oyashio current. They are typical wasp-waist ecosystems dominated by small pelagic species such as sardine and anchovy exhibiting large low-frequency fluctuations in biomass. Most studies have hitherto been on the variability of individual species such as sardine and anchovy; only a few have focused on the long-term variability of the fish assemblages. In this study, thirteen species ranging from small forage to large predatory species and from warm to cold water species were selected as indicators, and essential characteristics of the fish assemblages were analyzed based on fishery, oceanographic and climate datasets during the period from 1901 to 2010. Principal component analysis (PCA) of the catch of 13 indicator species showed evident decadal variation patterns with step changes in the first principal component (PC1) in the early-1910s, mid-1930s, early-1960s and late-1980s, and in the PC2 around the late-1920s, early-1940s and mid-1970s. PC3 showed abrupt changes around the early-1910s and mid-1930s, mid-1950 and mid-1960s, closely resembling those in PC1. The tipping points in PC1 and PC3 corresponded well with those of the Arctic Oscillation (AO) (mid-1930s and late-1980) and the Monsoon Index (MOI) (early-1910s, mid-1960s and late-1980s), while PC2 seemed associated with Pacific Decadal Oscillation (PDO) (early-1940s and mid-1970s). These regime shifts revealed by PC analysis indicated that the dominant variation modes in the fish assemblages of waters surrounding Japan were forced by decadal climate variability as inherent in AO, MOI and PDO. Ecological indicators such as mean trophic level showed decadal variation patterns which were influenced to a large degree by small pelagic species. The potential possibility of using ecological indicators to detect early warning signals of future regime shifts in the fish assemblages is discussed.

June 4, 18:00/S8-Oral-12698

### Inter-annual variability of Gulf Stream warm-core ring/continental shelf encounters and longfin squid (*Doryteuthis pealeii*) abundance fluctuations

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Studies show large inter-annual variability (IAV) of Gulf Stream warm-core-rings (WCRs), including their numbers, locations, and types of interactions with outer continental shelf waters. Analyses of WCR centers and radii from a 44-year (1973-2016) data set (N=21, 202) display strong IAV of encounters between WCRs and the outer continental shelf, especially between 65°-75°W, with a sharp decrease in encounter area east of 65°W. Temporal changes in the types of oceanographic analysis charts used throughout the 44-year analysis period may account for some of the variability prior to 1981 and after 2004. However, NOAA's Oceanographic Analysis and Jennifer Clark's "Gulf Stream" charts comprise a consistent dataset used over the 24-year core period (1981-2004) of this study. Results show WCR minimum (maximum) numbers of 15 (48) occurring during 1981 and 1992 (2003). Local maxima, *i.e.*, "hotspots", of WCR/continental shelf encounters occur on the outer shelf between 68-69° W (south of Georges Bank), 71-72°W (south of Montauk, NY), and a much-reduced maximum between 61-62°W (south of Nova Scotia). Longfin squid (*Doryteuthis pealeii*) is an important migratory species that displays large IAV in abundance over the U.S. Northeast Shelf Large Marine Ecosystem. Shoreward incursions of WCR water on-shelf and seaward entrainments of shelf water off-shelf may affect longfin squid temperature habitat, thus causing changes in inshore abundance during summer and over-wintering longfin squid abundance near the shelf slope front during winter. Ongoing work is exploring the relationship between WCR/continental shelf encounters and longfin squid abundance.



**June 8, 10:40/S8-Oral-13033**

### **Recent changes in shelfbreak exchange processes in the Middle Atlantic Bight**

Glen **Gawarkiewicz**<sup>1</sup>, Anna Malek Mercer<sup>2</sup>, Paula Fratantoni<sup>3</sup>, Robert Todd<sup>1</sup> and Avijit Gangopadhyay<sup>4</sup>

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The continental shelf in the northeastern U.S. has been warming for the past decade, influenced by extreme warming events such as those experienced during the first six months of 2012. One important aspect of the warming is the increasing role of offshore forcing by Gulf Stream Warm Core Rings. Recent measurements from the Ocean Observatories Initiative Pioneer Array shelfbreak observatory, are examined together with observations collected by commercial fishermen on the shelf to describe changes in the water masses occupying the continental shelf and slope. Specifically, these data are used to explore several extreme shelfbreak exchange events in which ring water penetrates considerable distances across the continental shelf. Some implications for the shelf ecosystem will be discussed.

**June 8, 11:00/S8-Oral-12931**

### **The influence of the Gulf Stream on Northwest Atlantic ecosystems**

Janet **Nye**<sup>1</sup>, Lesley Thorne<sup>1</sup>, Hyemi Kim<sup>1</sup>, Haikun Xu<sup>2</sup>, Young-Oh Kwon<sup>3</sup> and Terrence Joyce<sup>3</sup>

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In the Northwest Atlantic cool, low salinity waters from the Labrador Sea converge with the warm, salty waters of the Gulf Stream. The relative volume of these two water masses strongly influences the thermal regime of the Northeast US coast and is related to Atlantic Meridional Overturning Circulation (AMOC). In the past two decades, the position of the Gulf Stream as indicated by both sea surface temperature and temperature at depth has been correlated with changes in species distribution, biomass, fish recruitment, species assemblages and marine mammal strandings, but the mechanisms underlying these phenomena are just starting to emerge. Furthermore, although sea surface temperature in the North Atlantic has been shown to have high predictability at the basin-scale, there is little to no predictability at the scale of the Northeast US continental shelf. It is argued here that the position of the north wall of the Gulf Stream is the best leading indicator of oceanographic conditions and ecosystem endpoints on the Northeast US shelf and may serve to be an important indicator and predictor in the Northeast Atlantic at seasonal, decadal and multidecadal scales.

**June 8, 11:20/S8-Oral-13143**

### **Using NOAA's high-resolution global climate model to assess climate change impacts in the Northwest Atlantic**

Vincent **Saba**

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Global climate models assessed in the IPCC's fifth report have difficulty resolving the regional ocean circulation of the Northwest Atlantic due to coarse resolution. In order to decrease the uncertainty of climate change impacts on the region, models must improve simulations of key oceanographic features such as: the coastal separation point of the Gulf Stream, Labrador Current circulation, formation and transport of mesoscale eddies, as well as resolving topographic features that influence regional circulation (*i.e.* Georges Bank). Here I present the advantages and current use of a prototype, global high-resolution climate model (CM2.6) developed by NOAA's Geophysical Fluid Dynamics Laboratory. Research using CM2.6 for the Northwest Atlantic has included analyses of both ocean physics and marine resources. This model is now being widely used to project marine resource change in response to continued ocean warming in the Northwest Atlantic. I will present an overview of this research, which will include projections of ocean circulation, fish and zooplankton distribution, and predator-prey interactions.

**June 8, 11:40/S8-Oral-13017**

## **Climate-induced shifts in phenology: Case studies of fish, whales, and seabirds in the Gulf of Maine**

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The timing and intensity of warming and cooling cycles in the Gulf of Maine (GOM) in the Northwest Atlantic Ocean have undergone significant shifts associated with regional oceanographic and atmospheric patterns. These shifts have implications for highly migratory species that time recurring life events to coincide with preferred seasonal conditions and peaks in forage. This study quantifies phenological responses synthesized over a 20 year period through three regional case studies: 1) spring spawning migration of anadromous alewife (*Alosa pseudoharengus*), 2) spring habitat use by North Atlantic right (*Eubalaena glacialis*) and fin (*Balaenoptera physalus*) whales, and 3) spring-summer foraging conditions of nesting seabirds (*Sterna* sp.). Spring transition date (STD), an oceanographic metric of spring onset, was identified as a significant predictor of shifting phenology across species examined; however, responses varied in strength, directionality and spatial coherence. Earlier STDs were related to earlier run initiation dates for alewife moving into twelve coastal spawning ponds in Massachusetts. Right whale occupancy was negatively related to STDs in the western GOM, and positively related to STDs in the central and eastern GOM for fin whales; overall, date of maximum habitat use shifted later for right whales and earlier for fin whales by approximately a month. Later STDs in the eastern GOM predicted lower proportions of higher quality prey (fishes) and increasing proportions of lower quality prey (euphausiids) in seabird diets. These novel analyses provide new insights into higher trophic level species responses to climate variability, potential implications for resource mismatches and interactions with human activities.

**June 8, 12:00/S8-Invited-12610**

## **The Changing Character of Western Boundary Currents with Climate Change and the Implications for Fisheries**

Hassan **Moustahfid**<sup>1</sup> and Avijit Gangopadhyay<sup>2</sup>

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Marine species depend on boundary ocean currents for dispersal and for the completion of their life cycle. The western boundary currents are the hot-spots around the world in terms of heat transported and air-sea carbon fluxes. Recently, there has been an increasing interest to improve knowledge of ocean currents changes, as part of the global climate change, and the implications of such changes on re-shaping marine communities. Studies have shown strong changes in the intensity and position of the boundary currents. For example, the Kuroshio, the Agulhas and other western boundary currents are shifting their paths poleward (except the Gulf Stream) and thus the consequences of such changes for ecosystems and especially for marine productivity and fisheries are beginning to emerge. The impact of Arctic meltwater and North Atlantic Oscillation on the weakening Atlantic Meridional Overturning Circulation and a southward shifting Gulf Stream are being observed over a few decades now. Marine species are reacting to these changes, especially pelagic fish, and invertebrates' species. Poleward latitudinal shifts of present distributions which seem corroborated by recent observations, e.g. with Atlantic bluefin migrating further north in summer following the warming of water masses. Cephalopods and especially squid for example are increasing their abundance in the world oceans. In this talk, we will present a brief overview of the boundary currents in the world oceans and their observed responses to the continuing changes in climate for past few decades and how these changes are affecting marine productivity and fisheries including regime shifts.

**Keywords:** Western Boundary Currents, Climate Change, Fisheries, Regime shifts

**June 8, 13:40/S8-Oral-12860**

**Evaluating the utility of the Gulf Stream Index for predicting recruitment of Southern New England-Mid Atlantic yellowtail flounder**

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The justification for incorporating environmental effects into fisheries stock assessment models has been investigated and debated for a long time. Recently, a state-space age-structured assessment model which includes the stochastic change in the environmental covariate over time and its effect on recruitment was developed for Southern New England-Mid Atlantic yellowtail flounder (*Limanda ferruginea*). In this paper, we first investigated the correlations of environmental covariates with Southern New England-Mid Atlantic yellowtail flounder recruitment deviations. The covariate that was most strongly correlated with the recruitment deviations was then incorporated into the state-space model and alternative effects on the stock-recruit relationship were estimated and compared. For the model that performed best as measured by Akaike information criterion, we also compared the estimates and predictions of various population attributes and biological reference points with those from an otherwise identical model without the environmental covariate in the stock-recruit function. We found that the estimates of population parameters are similar for the two models but the predictions differed substantially. To evaluate which model provided more reliable predictions, we quantitatively compared the prediction skill of the two models by generating two series of retrospective predictions. Comparison of the retrospective prediction pattern suggested that from an average point of view, the environmentally explicit model can provide more accurate near-term recruitment predictions especially the one year ahead recruitment prediction. However, the accuracy of the near-term recruitment prediction from the environmentally explicit model was largely determined by the accuracy of the corresponding environment prediction that the model provides.

**June 8, 14:00/S8-Oral-13062**

**How might climate change impact fisheries management and marine protected areas?**

John Quinlan

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Fisheries management and protection of threatened or endangered species often rely on imposing usage rules for specific areas of the coastal ocean. These areas are important for sustainably managing living marine resources and they often provide high-value ecological function. Climate related changes in temperature, dissolved oxygen, pH, and other variables could alter the ability of such areas to address the intended management goal. Here, projections from climate models are used to assess the direction and magnitude of environmental change expected in such areas along the eastern seaboard of the United States from the Gulf of Mexico to New England. The project examines essential fish habitat, habitat areas of particular concern, and areas closed to fishing. Detailed case studies are provided.

**June 8, 14:20/S8-Oral-12940**

**Fisheries in a changing world: Examples from the Northeast U.S. Shelf**

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As a western boundary current system, the Northeast U.S. Shelf Large Marine Ecosystem is one of the fastest warming shelf ecosystems in the world and rapid warming is projected to continue in the future. The large-scale changes in climate are causing direct changes in the distribution and productivity of the region's fisheries. These impacts will continue for the foreseeable future (*e.g.*, decades) independent of any national or global efforts to address greenhouse gas emissions. Changes in climate are also affecting a number of other components of the ecosystem - including humans - that are interacting with marine fisheries. The distribution of marine mammals and sea-turtles are changing, which is altering the interaction with fisheries. Sea-level rise and storm surge are impacting coastal infrastructure, thereby affecting shore-based aspects of fisheries. Ocean wind-energy development is resulting in renewable energy, but interactions with fisheries are just beginning to be understood. Aquaculture is developing rapidly, primarily in coastal waters, but possibly on the shelf; interactions between aquaculture and fisheries in ocean waters are not well-defined. The tourism and recreation sector is very strong

in the region, in part reliant on recreational fishing and in part reliant on access to the ocean and services derived from the ocean. In the rapidly changing and highly populated Northeast U.S. Shelf Ecosystem, there is the need to develop ecosystem-based approaches to management to understand the interactions among sectors, identify the trade-offs that exist, and consider those that may exist in the future.

## **S9: Drifting into the Anthropocene: How will pelagic marine ecosystems be affected and what are the biogeochemical and lower trophic consequences**

**June 4, 11:35/S9-Invited-12893**

### **Marine Ecological Time Series: What are they telling us about the ocean?**

Laura **Lorenzoni**<sup>1</sup>, Todd O'Brien<sup>2</sup>, and the IGMETS Community<sup>3</sup>

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Ship-based biogeochemical time series provide complex and high-quality biological and chemical measurements that are needed to detect and assess climate change associated impacts on marine food webs, and to ultimately improve understanding of changes in marine ecosystems. While the spatial 'footprint' of a single time series may be limited, coupling observations from multiple time series with synoptic satellite data can improve our understanding of critical processes such as ocean productivity, biogeochemistry and carbon fluxes on larger spatial scales. The IOC-UNESCO International Group for Marine Ecological Time Series (IGMETS) continues to analyze over 340 open ocean and coastal datasets, ranging in duration from five to fifty years. These contributing time series are highlighted in the IGMETS informational database and GIS (<http://igmets.net/metabase>). IGMETS' cross-time-series analysis has already yielded important insights on climate trends, and has set a baseline of global and regional observations at an unprecedented scale. The generalized warming trend observed by IGMETS across most oceans is often accompanied by shifts in the biology and biogeochemistry (*i.e.* oxygen, nutrients). Variability in temperature and productivity are often driven by regional and temporal expressions of large-scale climatic forcing and atmospheric teleconnections, which has important implications for ecosystem services and future ocean sustainability. Understanding marine biogeochemical and ecological changes at a global scale remains in the forefront of the scientific agenda worldwide, and IGMETS is expanding its analyses to include additional years of data, new participants and time series, and new variables so as to achieve this goal.

**June 4, 12:05/S9-Oral-12670**

### **Zooplankton community changes on the Canadian northwest Atlantic continental shelves during recent warm years**

Catherine L. **Johnson**<sup>1</sup>, Stéphane Plourde<sup>2</sup>, Pierre Pépin<sup>3</sup>, Emmanuel Devred<sup>1</sup>, David Brickman<sup>1</sup>, David Hebert<sup>1</sup>, Peter S. Galbraith<sup>2</sup>, Eugene Colbourne<sup>3</sup>

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The Canadian northwest Atlantic continental shelf system is located in a transition zone between arctic and north temperate waters and is characterized by strong annual-scale temperature variation and by a strong latitudinal temperature gradient from seasonally ice-covered waters on the Labrador and Newfoundland shelves and in the Gulf of St. Lawrence to warmer, ice-free waters of the western Scotian Shelf. Zooplankton biomass in this region has historically been dominated by large, energy-rich copepods of the genus *Calanus*, with *Calanus finmarchicus* reaching its southern limit in the Gulf of Maine and *Calanus hyperboreus* at the southern limit of its reproductive range in the Gulf of St. Lawrence. Over the last century, shelf waters have exhibited interdecadal shifts between warmer and cooler conditions, overlain with a long term warming trend that has become more pronounced since the mid-1950's and culminated in unusually warm ocean temperatures in the last 5-7 years, particularly on the

Scotian Shelf. Zooplankton have been consistently sampled throughout the Canadian northwest Atlantic shelves since 1999, making it possible to detect a zooplankton community shift in the last 5-7 years toward higher abundances of small copepods and non-copepod taxa at the expense of lower abundances of large, energy-rich *Calanus* copepods, associated with warm ocean conditions and reductions in sea ice. The zooplankton community change will be discussed in the context of environmental changes and implications for productivity of higher trophic levels.

**June 4, 12:25/S9-Oral-13170**

### **Long term changes in the controlling factors of phytoplankton in the Southern North Sea**

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Perhaps one of the most pertinent questions on the effects of Change in the ocean is how single species react to shifts in drivers and what the consequences are for pelagic foodwebs. Here we present our results on phenological shifts in phytoplankton species and changes in interactions between zooplankton and phytoplankton in the Southern North Sea. This work is based upon the historical daily pelagic and Wadden Sea Long Term Data sets (Helgoland Roads and Sylt Bight, respectively) of the Biologische Anstalt Helgoland (Alfred-Wegener-Institute). We show how the nutrient relationships, light penetration depth and temperature shifts affect species phenology in the southern North Sea. We show that different species react differently to observed shifts in light and temperature in different seasons. We link the grazing capacity to the food quality of the phytoplankton and present the clear increase in diversity in terms of environmental variability and long-term trends. These results are discussed in terms of greater hydrographic shifts in the North Sea and global shifts in temperature.

**June 4, 14:00/S9-Oral-12954**

### **Multi-decadal variability in coccolithophore abundance in the North Pacific Subtropical Gyre**

Joo-Eun Yoon and Il-Nam Kim

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Coccolithophores, the predominant calcifying phytoplankton in modern ocean that plays a key role in the marine carbon cycle, are considered particularly susceptible to ocean acidification resulting from the addition of anthropogenic CO<sub>2</sub> to the upper ocean. Contrary to the prevailing paradigm, recent studies showed that a long-term basin-scale increase in coccolithophore abundance occurred in the North Atlantic Subtropical Gyre (NASG) and this variation have responded positively to increased CO<sub>2</sub> invasion. However, there has as yet been no findings on basin-scale coccolithophore responses to recent environmental changes in the world's largest ecosystem, North Pacific Subtropical Gyre (NPSG). Here, we present the long-term trend in NPSG coccolithophore abundance based on Hawaii Ocean Time-series monthly data (i.e., climate indices, temperature, salinity, nutrients, carbonate system parameters, and phytoplankton pigments) observed over the period 1988–2015 at Station ALOHA (22°45'N, 158°00'W), by combining with concurrent satellite data (i.e., particulate inorganic carbon and phytoplankton composition). The trend showed an increase in integrated coccolithophore abundance (surface to ~160 m depth) between 1988–2004, followed by a decrease through 2015. However, dissolved inorganic carbon (DIC) concentrations increased continuously over the entire period from 1988 to 2015. DIC signal was significantly coupled with the earlier increasing NPSG abundances while decoupled from the more recent decrease (since ~2005). Interestingly, the 2005–2015 NPSG abundance decrease contrasts the increase in the NASG. Here, we discuss the relative importance of environmental variables that have caused these changes in coccolithophore abundances in the NPSG and the mechanisms that drive the difference between two basins.

**June 4, 14:20/S9-Oral-13196**

**Increased variability in the copepod community structure, diversity, and biomass in the northeast Pacific (Newport, Oregon, USA) over the last 21 years**

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Hydrographic and zooplankton data have been collected every two weeks to monthly for the past 21 years at a nearshore (60 m water depth) station off Newport, OR in the northeast Pacific. This effort has shown that copepod species composition exhibits a strong seasonal cycle and that inter-annual variations in specific copepod communities are driven largely by basin-scale processes opposed to processes associated with local upwelling. Over this time period, the PDO is no longer decadal, rather it changes sign more rapidly. Likewise, ENSO is now recognized to have two flavors – eastern Pacific and central Pacific with flavor-dependent time lags in the timing of the physical and biological response in the northeast Pacific (44.6°N). Sea surface temperature generally tracks both PDO and ENSO, but salinity does not and appears to be out of synch. Similarly, copepod species richness and total copepod biomass, and the biomass of different copepod groups are fluctuating.

**June 4, 14:40/S9-Oral-12667**

**Lower trophic consequences with bottom-up effects: a decline in primary production in the North Sea over 25 years, associated with reductions in zooplankton and fish recruitment**

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Given that phytoplankton primary production is at the base of the marine foodweb, any climate-related changes in production are likely to have direct or indirect effects on the higher trophic levels, from zooplankton to fish to marine mammals. This study reveals for the North Sea which has recently warmed substantially, that primary production has declined significantly over the period 1988–2013, based on a new time-series of in situ observational data on gross primary production. Within the North Sea, primary production differs in magnitude between six hydrodynamic regions with some being much more productive than others. Sea surface warming and reduced riverine nutrient inputs are found to be likely contributors to the declining levels of primary production. In turn, significant correlations are found between primary production and the dynamics of higher trophic levels including (small) copepods and a standardised index of fish recruitment, averaged over seven stocks of high commercial significance in the North Sea. Given positive (bottom-up) associations between primary production, zooplankton abundance and fish stock recruitment, this study provides strong evidence that if the decline in primary production continues, knock-on effects upon the productivity of fisheries are to be expected unless these are managed effectively and cautiously.

**June 4, 15:00/S9-Oral-12675**

**Decadal changes in carbon budget of a SW Atlantic estuary: Coupling between a drop in phytoplankton biomass and the erosion of salt marshes**

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Coastal environments have undergone fast changes in recent decades driven by natural and human impacts. The non-linear responses of biological communities to multiple-environmental stressors at the land-sea interface underscore the need for continuous observations at local/regional scales. In the Bahía Blanca Estuary, Argentina, a long-term monitoring program displayed a decrease in phytoplankton biomass concomitant with decadal environmental shifts where water turbidity, dissolved inorganic nutrients, precipitation and wind mediate different hierarchical effects in shaping plankton response. Likewise, the analyses of land cover, surface elevation profiles, and soil surveys revealed that important areas of *Sarcocornia perennis* marshes eroded between 1967 and 2015 releasing organic carbon from the soil pool. The observed marsh loss and the erosion of soft sediments are in agreement with the present rising trends in relative sea level. Increased water turbidity and reduction in water transparency in the shallow inner part of the estuary are related to the intensification of dredging operations and marsh erosion, which are major sources of suspended solids and nutrients to the water column. In addition, changes in wind and the observed trends in wetland loss and enhanced turbidity are tightly coupled to negative effects on the occurrence of the winter-early spring phytoplankton bloom, transposing the micro- and mesozooplankton communities. Given the role that phytoplankton and wetland soils play in the global carbon cycle, this long-term monitoring program provides an example of the underlying human and natural mechanisms controlling the production in marine ecosystems.

**June 4, 15:20/S9-Oral-12805**

**Linking long-term changes of pelagic microbial communities to fluctuations in climate and hydrological regime in a coastal ecosystem (Adriatic Sea)**

Patricija **Mozetič**, Boris Petelin, Janja Francé, Vesna Flander-Putrlje, Katja Klun, Matjaz Licer, Tinkara Tinta, Valentina Turk and Vlado Malacic

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Coastal ecosystem of the northern Adriatic Sea is characterized by the complexity of hydrological, oceanographic and biological features owing to geomorphologic traits, large temperature fluctuations, and substantial freshwater discharges. The three decades long time-series (1985-2016) of the water-column abiotic properties and microbial communities' dynamic were used to discern multiyear trends from natural ecosystem variability. The most noticeable trend was the increase in seawater temperature, especially evident in the last decade both in the surface layer (0.14°C year<sup>-1</sup>) and above the bottom (0.12°C year<sup>-1</sup>). Instead of a similar straightforward trend, three distinct surface salinity regimes were detected with an evident seasonal pattern: 1985-2002, 2003-2007 and 2008-2015. These periods exactly matched the inverse regimes of the cumulative annual discharge of the main rivers. All these changes have affected the nutrient status of the basin, primarily nitrate concentrations in the surface layer. The observed negative trends of ammonia and silicate from the mid-2000s onwards coincided with a substantial drop in phytoplankton biomass (mean chlorophyll a concentration of the period before and after 2005 was 1.04 µg l<sup>-1</sup> and 0.56 µg l<sup>-1</sup>, respectively) and changes in the phytoplankton community structure. The latter were related to an increase in concentrations of photosynthetic pigments characteristic for small autotrophs (cyanobacteria, chlorophytes). Coupling these findings with the increasing and temperature-dependent bacterial carbon production would suggest that in the last decade the organic matter was largely driven through the microbial loop before entering the classical food web in this coastal ecosystem.

**June 4, 15:40/S9-Oral-12911**

**Anthropogenic effects on biogeochemical processes, carbon export and sequestration: Influence of bacteria-particle interactions on oceanic carbon cycling**

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Anthropogenic activities modulate a suite of oceanic properties, including temperature, circulation patterns, and nutrient inputs and distributions. These activities in turn can alter biogeochemical processes and fluxes that influence, and are influenced by marine food webs. For example, atmospheric CO<sub>2</sub> that is transferred into the ocean is transformed by the pelagic food webs back to CO<sub>2</sub>, or into organic material that can be exported from the surface and sequestered in the deep ocean. Biologically-driven carbon export and sequestration is mediated by the biological carbon (i.e. soft tissue; BCP), carbonate and microbial carbon pumps (MCP). Heterotrophic microbes have critical roles in the cycling and transformation of the organic material that is produced in the surface layer, and which ultimately sinks or is transported through the water column. Here we have assembled and analyzed a comprehensive database on particle-attached (PA) and free-living (FL) bacterial processes, and associated environmental variables for the World Oceans. Free-living and PA bacteria are an interacting continuum rather than independent communities, they are physiological and phylogenetically distinct, and although PA bacteria are generally larger than FL bacteria, they account a smaller but significant fraction of the total bacterial biomass (~3-25%) and production (~5-35%). Their relationships and patterns vary with, region and depth with the PA/FL ratio being generally greater at low temperatures and depth. Free-living and PA bacteria are an interacting continuum rather than independent communities. The particle characteristics select for bacterial phylotypes and metabolic characteristics and this has a profound influence particle degradation and remineralization and consequently the balance between BCP and MCP, and the spatial patterns of carbon export and sequestration.

**June 4, 16:00/S9-Oral-13076**

**Natural and anthropogenic drivers of organic and inorganic carbon dynamics in the Gulf of Maine, USA**

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Global anthropogenic warming has resulted in a considerable increase in Arctic ice melt and freshwater input to the North Atlantic. As a result, the Gulf of Maine is experiencing substantial decadal changes in water column hydrography, biogeochemistry and planktonic ecosystem structure. Gulf of Maine researchers have documented significant freshening, a nutrient regime shift, changes in production and plankton community composition, decreases in particulate organic carbon delivery rates, and impacts on calcium carbonate precipitation/dissolution rates. An integration of a variety of geochemical and biological data sets will be presented to illustrate the linkages between drivers and specific effects on the coupled organic and inorganic carbon pumps in this shelf sea system.



**June 4, 16:40/S9-Oral-13097**

**Evidence of bifurcations (regime shift) in marine plankton communities in relation to increasing temperature, resulting in recruitment failure in fish**

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An annual beach seine survey, which has been carried out along the south coast of Norway since 1919, shows repeated incidences of abrupt and persistent recruitment failures in spring spawning gadoid fishes, both locally and regionally. Before 2000, these events took place during increasing nutrient loads, whereas the most recent event (~2002) occurred in relation to decreasing nutrient loads, but increasing temperature. Both direct and indirect evidence suggest that the recruitment failures were caused by shifts in the plankton community that deprived young of the year (YOY) gadoids of their staple zooplankton prey.

Small fishes that live for only one year (mainly gobies) dominate the biomass in shallow waters in this area. They spawn in summer and become highly abundant in late summer/early autumn. They are important prey for a variety of predators, including YOY gadoids during autumn and winter. However, as these small species slip through the meshes of the traditional seine, little is known about their fate after 2002. In 2016 and 2017, we repeated a study from 1997-1999 of these small species. Peak abundance, which occurs in the autumn, dropped by more than 90% in 2016 and 2017. Hence, the shift in the plankton community around 2002 seems to have affected recruitment of small summer spawning species too. For the spring spawning gadoids, the shift appears to have had a double negative impact on recruitment, first by reduced survival when depending on zooplankton, and then by reduced survival during the winter when depending on small fish.

**June 4, 17:00/S9-Oral-12635**

**Decadal environmental changes in the Newfoundland and Labrador ecosystem**

Frédéric **Cyr** and Pierre Pépin

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Newfoundland and Labrador shelves host one of the world's most important historical fishing grounds. Being located on a crossroads of the Atlantic meridional overturning circulation (AMOC), they are specially affected by climatic-related changes in large-scale ocean circulation. A growing body of evidence suggests that sustained circulations changes of the AMOC (including slowing downs) occur at multi-decadal and shorter time scales. Such circulation changes impact not only the regional climate, but also the overall water masses composition, with consequences on physical conditions, nutrient availability, oxygen content, etc. Although of global significance (e.g., for fish habitats), the details of these changes are still largely unknown in the oceanographic community. Systematic hydrographic observations of this system have been carried out by Canada and other countries since 1948. In Canada the observational program was reinforced in 1999 with the creation of the Atlantic Zone Monitoring Program (AZMP), ensuring enhanced seasonal coverage and new biogeochemical observations. Here we review nearly 7 decades of oceanic observations, with an emphasis on climate-related changes, as well as low frequency variability and cycles. The relationships between the hydrodynamics and the biochemical measurements is discussed as well as the possible long-term effects on the ecosystem.

**June 4, 17:20/S9-Oral-12650**

**Using optimal and realized habitat models to assess the underlying mechanisms of *Calanus* population responses to future climate change in the northwest Atlantic**

Stéphane **Plourde**<sup>1</sup>, Caroline Lehoux<sup>1</sup>, Frédéric Maps<sup>2</sup>, Pierre Pépin<sup>3</sup>, Catherine L. Johnson<sup>4</sup>, Zeliang Wang<sup>4</sup> and David Brickman<sup>4</sup>

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During the last decade, several habitat and niche models were developed to predict future changes in spatial distributions of the dominant planktonic copepod species of the genera *Calanus* in response to ocean warming in the north Atlantic. Here, we combined realized and optimal habitat models based on abundance and life traits respectively to estimate potential changes in populations' abundance and to assess the underlying dynamics of *Calanus* responses to future climate change in the northwest Atlantic. Firstly, realized habitat models were built with depth-integrated plankton net abundance data collected during the 1999-2012 period in the northwest Atlantic by the Atlantic Zone Monitoring Programme (AZMP). Secondly, optimal habitat models were used to characterize the response of key individual and population dynamics parameters to environmental conditions during the active (mortality/survival during egg-C1, late stages body size) and dormant (metabolism and diapause duration) phases of *Calanus* life cycle. Using these models, future changes in abundance and dynamics of *Calanus* species were then estimated using a climatology of a set of indices describing environmental conditions in the surface and deep habitats for the 1999-2012 (present) and 2066-2085 (future) periods derived from a climate run of the NEMO-OPA model using the RCP 8.5 scenario. Results were used to describe how changes in distribution, abundance and phenology of *Calanus* species towards the end of the present century could be explained by key processes occurring at various stages of their life cycle.

**June 4, 17:40/S9-Oral-13182**

**Investigating plankton size-spectra dynamics using a global trait-based ecosystem model**

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Marine ecosystems play a key role in climate processes such as air-sea CO<sub>2</sub> fluxes via the biological pump, but a major gap in our ability to model these impacts lies in the representation of plankton food-web dynamics, which are complex and difficult to generalize across ecological regimes. Size-structured plankton models have been utilized to varying degrees within the global domain, but few have been incorporated into biogeochemical models for climate-scale investigations. Here we develop a global trait-based ecosystem model utilizing variations in size, biogeochemical function, and zooplankton feeding selectivity within the modular Marine Biogeochemical Library (MARBL), embedded within the Community Earth System Model (CESM) Ocean General Circulation Model. With nine phytoplankton and six zooplankton spanning a range of sizes from picoplankton to macro-zooplankton, we investigate the diversity and emergent size-structure of plankton communities under various physical forcings, as well as the implications of changing the nature of trophic links on the rate and magnitude of nutrient cycling. We also prototype the inclusion of validation datasets of plankton size structure from *in-situ* plankton imaging systems. These explorations within trait-space will inform the development of more realistic ecosystem models for climate change studies.

**June 4, 18:00/S9-Oral-13155**

## **Coccolithophore growth and calcification in a changing ocean: Insights from Community Earth System Model simulations**

Kristen Krumhardt<sup>1</sup>, Nicole **Lovenduski**<sup>1</sup>, Keith Lindsay<sup>2</sup>, Matthew Long<sup>2</sup>, and Michael Levy<sup>2</sup>

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Coccolithophores are the most abundant calcifying phytoplankton in the ocean. These tiny primary producers substantially contribute to global ocean calcification, ballast organic matter to the deep sea, form part of the marine food web base, and influence ocean-atmosphere CO<sub>2</sub> exchange. Despite these important impacts, coccolithophores are not explicitly simulated in most Earth system models. Here we present global simulations of the Community Earth System Model (CESM) with coccolithophores as an explicit phytoplankton functional type. This is the first explicit coccolithophore parameterization in an Earth system model that includes the influence of changing carbonate chemistry on coccolithophore growth and calcification. We implement unique relationships for coccolithophore growth and calcification over environmental gradients of temperature, nutrient concentrations, and CO<sub>2</sub>. These relationships were derived from a wide compilation of physiological laboratory experiments and field observations across multiple coccolithophore species. We show that coccolithophore growth is stimulated by increasing temperature and CO<sub>2</sub> concentrations, especially in certain regions such as the North Atlantic and Southern Ocean. In general, however, increases in coccolithophore biomass are accompanied by decreases in calcification stemming from ocean acidification. Decreased calcification is somewhat modulated by increasing nutrient limitation from warming-induced ocean stratification, shown to increase the proportion of CaCO<sub>3</sub> production relative to photosynthesis in coccolithophores. Overall, from present-day to future, high-CO<sub>2</sub> conditions, coccolithophores shift their global geographical distribution and show reduced calcification in most regions. These results highlight how multiple simultaneous changes in the marine environment modulate biological responses on a global scale.

## S10: Management and Conservation of Species on the Move

June 6, 11:00/S10-Invited-12768

### Ocean currents and herbivory drive macroalgae-to-coral community shift under climate warming

Naoki H. Kumagai<sup>1</sup>, Jorge García **Molinos**<sup>2</sup>, Hiroya Yamano<sup>1</sup>, Shintaro Takao<sup>3</sup>, Masahiko Fujii<sup>4</sup> and Yasuhiro Yamanaka<sup>4</sup>

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Recently reported community shifts from temperate macroalgae to tropical corals, opposing the well-known shifts from corals to algae, offer conservation potential for corals at the expense of macroalgae under climate warming. Although such community shifts are expanding geographically, our understanding of the driving processes is still limited. Here, we reconstruct long-term climate-driven range shifts in 45 species of macroalgae, corals and herbivorous fishes from over 60 years of records (mainly 1950–2015) stretching across 3,000 km of the Japanese archipelago from tropical to subarctic zones. Prediction models combining the effects of warming and ocean currents consistently explained observed community shifts significantly better than those relying on climate velocities alone. Corals and herbivorous fishes performed better at exploiting opportunities offered by this interaction. The contrasting range dynamics for these taxa suggest that ocean warming is promoting macroalgal-to-coral shifts both directly by increased competition from the expansion of tropical corals into the contracting temperate macroalgae, and indirectly via overgrazing by the expansion of tropical herbivorous fish. Beyond individual species' effects, our results provide novel evidence on the important role that the interaction between climate warming and external forces conditioning the dispersal of organisms, such as ocean currents, can have in shaping community level responses, with concomitant changes to ecosystem structure and functioning. Further, we found that community shifts from macroalgae to corals might accelerate with future climate warming, highlighting the complexity of managing these evolving communities under future climate change.

June 6, 11:40/S10-Oral-12879

### Climate-mediated tropicalisation of temperate reefs: Should we care?

Adriana **Vergés**<sup>1,2</sup>, Erin McCosker<sup>1</sup>, Thomas Wernberg<sup>3</sup>, Mariana Mayer-Pinto<sup>1,2</sup> and Peter Steinberg<sup>1,2,4</sup>

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Temperate reefs from around the world are becoming tropicalized, as warm-water species shift their distribution towards the poles in response to warming. This is already causing profound changes in species assemblages and a shift in dominant foundation species. Canopy seaweeds such as kelp that typically dominate temperate reefs are being replaced by either low biomass turf algae or corals, with cascading impacts on associated species. Here, we investigate the consequences of this tropicalisation for the ecosystem functions that underpin the goods and services that humans derive from temperate reefs, and what that means for the management of our marine environment. We discuss expected changes in biodiversity, primary productivity, benthic fisheries productivity, carbon sequestration and nutrient cycling due to either a 'kelp to corals' or a 'kelp to turf algae' shift. We outline management practices for these two differing trajectories that can either mitigate predicted functional changes or make the most of potential new opportunities. We consider the socio-economic, ethical and ecological implications and the risks associated with new management approaches that differ in the severity of proposed interventions (e.g. from MPAs to assisted evolution) as well as time frame for action.

**June 6, 12:00/S10-Oral-13229**

**Characterizing and predicting Aquatic Invasive Species distributions: Reconciling large-scale model predictions with small-scale observations and incorporating climate change scenarios**

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Marine invasions, like other stressors, seldom are uniform and some locations will have conditions amenable to supporting large populations of invaders while others will not. Since impacts often are closely related to population sizes for many invasive species, it is important to identify the amount of habitat capable of supporting populations at an “invasive” level and these habitats should form core monitoring sites. Here we characterize the relative density of European green crab (*Carcinus maenas*) populations in both Barkley and Quatsino Sounds, along the west coast of Vancouver Island, British Columbia along with environmental measures potentially influencing the distribution of this species. In addition, we have been examining how climate change might alter the distribution of this high risk invader at different spatial scales. Currently, this invader is spreading largely via natural larval dispersal in British Columbia from well-established populations but climate change may alter invasion vectors and pathways. These changes, especially if overcoming natural biogeographical barriers to dispersal, combined with refined environmental model predictions should allow managers to better target limited resources for early detection of new invaders in the most susceptible environments.

**June 6, 12:20/S10-Invited-12829**

**Can we adapt to species on the move?**

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Recent shifts in the geographic distribution of marine species have already posed challenges for living marine resource management, but understanding the magnitude, timescales, and species that have been and that will be most affected can provide practical information for proactive adaptation. We are developing a suite of tools to facilitate the adaptation process in marine conservation and in fisheries management, including the OceanAdapt website that tracks ongoing shifts in the spatial distribution of >650 marine fish and invertebrates in North America. After validation with hindcasts against historical data, we have also modeled future thermal habitats and uncertainty over the 21<sup>st</sup> century for marine animals in North America at spatial scales useful to regional management and conservation efforts. These projections help identify where and when novel fisheries may emerge, and where traditional fisheries may decline or disappear. Results suggest that one third of species may be replaced within existing Marine Protected Areas (MPAs) by the end of the century, but those networks of protected areas and fishing zones can produce meaningful reductions in climate exposure without requiring substantial tradeoffs for other ocean users. While climate change will severely disrupt many human activities, we find a strong benefit to proactively planning for long-term ocean change.

**June 6, 14:00/S10-Oral-12718**

**Projected distribution and diversity patterns of marine taxa in the Pacific Arctic under future climate**

Irene D. **Alabia**<sup>1</sup>, Jorge García Molinos<sup>1</sup>, Sei-Ichi Saitoh<sup>1</sup>, Takafumi Hirata<sup>2</sup>, Toru Hirawake<sup>3</sup> and Franz J. Mueter<sup>4</sup>

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Future climatic changes are expected to impact species distributions and diversity patterns in marine ecosystems. Here, we investigated possible consequences of changes in habitat and diversity patterns of fish and invertebrate species due to ocean warming and sea ice loss in the Eastern Bering and Southern Chukchi seas, the climate-sensitive regions of the Pacific Arctic. Changes in current species-specific habitat patterns and biodiversity components (*e.g.* species richness and beta-diversity) were examined under two contrasting CMIP5 climate scenarios (RCPs 4.5 and 8.5). The ensemble models were developed using summer catch data (June-August) from NOAA bottom trawl surveys and several relevant environmental covariates (winter sea surface temperature, sea ice concentration, and depth). These models were then used for predicting species-specific habitat suitability across the study region under present-day and future climatic conditions. Results from these analyses will have clear implications for the management and conservation of marine resources under future climate change.

**June 6, 14:20/S10-Oral-12758**

**Mechanistic understanding of climate driven range shifts: using thermal tolerances of rock lobster to predict future range shifts**

Samantha **Twina**<sup>1</sup>, Chris Carter<sup>1</sup>, Quinn Fitzgibbon<sup>1</sup>, Alistair Hobday<sup>2</sup>, Gretta Pecl<sup>1</sup> and Eva Plagányi<sup>3</sup>

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Ocean warming is affecting marine species worldwide, with one of the most pervasive effects being alterations to species geographical distributions. Understanding what drives these 'range shifts' is key to predicting what may happen with future ocean warming. This study takes a mechanistic approach to understanding climate-driven range shifts, using previously examined measures of the thermal performance of aerobic metabolism and escape responses of two species of lobster; *Jasus edwardsii*, a common Tasmanian species of spiny rock lobster, and *Sagmariasus verreauxi*, a species of spiny rock lobster suspected of extending its range into and further south in Tasmania, Australia. These measures give insights into aerobic performance, a key component of organismal energy budgets, as well as the performance of escape responses, which are critical for survival. Using these measures of performance, we developed a model of intermediate complexity for ecosystem assessments (MICE). The MICE incorporates the physiological data available for the two lobster species with fisheries and environmental data to improve understanding of the complexity of environmental changes influencing species range shifts in South East Australia. Simulations were used to evaluate how the populations of both species may react under future ocean warming scenarios, in terms of both changes in biomass and in the extent of range extension into Tasmanian waters. The results show increases in the biomass and extent of the distribution range of *S. verreauxi* in Tasmanian waters, but also interestingly that *J. edwardsii* may remain a dominant competitor in the face of ocean warming.

**June 6, 14:40/S10-Oral-12734**

### **Evaluating future fisheries management scenarios using combined downscaled climate, ocean circulation, and habitat suitability models**

Mitchell A. **Roffer**<sup>1</sup>, Barbara Muhling<sup>2</sup>, Aaron Adams<sup>3</sup>, Sang-Ki Lee<sup>4</sup>, Yanyun Liu<sup>5</sup>, Xiangming Zeng<sup>6</sup>, Ruoying He<sup>6</sup>, John T. Lamkin<sup>7</sup>, Frank Muller-Karger<sup>8</sup>, Matthew Upton<sup>1</sup> and Gregory Gawlickowski<sup>1</sup>

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Climate, ocean circulation, and fish habitat suitability models were linked and downscaled to regions including the North Atlantic Ocean, Gulf of Mexico and Caribbean Sea to examine possible scenarios of movement, distribution and survival of larvae on highly migratory oceanic species such as Atlantic bluefin tuna (*Thunnus thynnus*), and coastal estuarine dependent species such as bonefish (*Albula vulpes*). The scenarios suggest that north Atlantic bluefin are likely to change their primary spawning grounds from the Gulf of Mexico to habitats that are likely to be more favorable in the future, e.g. Bahamas and north to the Middle Atlantic Bight. Scenarios show that bonefish may extend their range from the Caribbean Sea to coastal areas such as North Carolina, South Carolina, and the Gulf of Mexico. Potential changes in the location of spawning and of fisheries suggest the need for new stock assessment surveys and management strategies. While bluefin is managed internationally through the International Commission for the Conservation of Atlantic Tunas (ICCAT), bonefish are managed by each coastal country and state. These species provide examples of why protected areas will need to be relocated as will as changes in the temporal and spatial allocation of quotas nationally and internationally.

**June 6, 15:00/S10-Oral-12671**

### **Famine in a time of plenty – a recent paradox in the Benguela upwelling system**

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In the early 20<sup>th</sup> century, plentiful seabirds in the Benguela ecosystem provided lavish quantities of organic fertiliser to farmers and copious supplies of high-quality eggs to confectioners. Such onslaughts on their habitations and offspring were barely sustainable, yet scarcely could they have imagined that worse would yet befall them. A rapid development of forage fisheries would plunder their food as well. So it was that seabirds continued to decrease until the century had almost concluded. Then wondrously, it seemed, their fortunes would improve. As the present century began, an abundance of food again filled the oceans and a recovery of seabird populations was initiated. But changes were afoot and, although anchovies remained bountiful, it would not be long before all seabird species that fed primarily on the harvested forage would suffer high mortality and reduced breeding success, primarily as a result of food scarcity, and all be classified as Endangered. In such a time of plenty, what caused the famine? We will consider how altered distributions and availability of forage species and behavioural inertia amongst the seabird predators led to this unfortunate state and discuss the implications for ecosystem-based management in changing marine systems.

June 6, 15:20/S10-Oral-12843

### Metapopulation tracking juvenile penguins reveals an ecosystem-wide ecological trap

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Climate change and fisheries are transforming the oceans, but we lack a complete understanding of their ecological impact. Environmental degradation can cause maladaptive habitat selection, inducing ecological traps with profound consequences for biodiversity. However, whether ecological traps operate in marine systems is unclear. Large marine vertebrates may be vulnerable to ecological traps, but their broad-scale movements and complex life histories obscure the population-level consequences of habitat selection. We satellite tracked postnatal dispersal in African penguins (*Spheniscus demersus*) from eight sites across their breeding range to test whether they had become ecologically trapped in the degraded Benguela ecosystem. Bayesian state-space and habitat models show that penguins traversed thousands of square kilometers to areas of low sea surface temperatures (14.5°C–17.5°C) and high chlorophyll-*a* (~11 mg m<sup>-3</sup>). These were once reliable cues for prey-rich waters, but climate change and industrial fishing have depleted forage fish stocks in this system. Juvenile penguin survival is low in populations selecting degraded areas, and Bayesian projection models suggest that breeding numbers are ~50% lower than if non-impacted habitats were used, revealing the extent and effect of a marine ecological trap for the first time. These cascading impacts of localized forage fish depletion — unobserved in studies on adults — were only elucidated via broad-scale movement and demographic data on juveniles. Our results support suspending fishing when prey biomass drops below critical thresholds and suggest that mitigation of marine ecological traps will require matching conservation action to the scale of ecological processes.

June 6, 15:40/S10-Oral-12955

### Reconciling ocean connectivity and hydroclimate with the management of transboundary metapopulations

Manuel [Hidalgo](#)<sup>1,2</sup>, Vincent Rossi<sup>3,4</sup>, Pedro Monroy<sup>3</sup>, Enrico Ser-Giacomi<sup>5</sup>, Emilio Hernández-García<sup>3</sup>, Beatriz Guijarro<sup>1</sup>, Enric Massutí<sup>1</sup>, Francisco Alemany<sup>1</sup>, Angélique Jadaud<sup>6</sup>, José Luis Perez<sup>2</sup> and Patricia Reglero<sup>1</sup>

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Worldwide overexploitation of marine resources challenges emerging solutions that incorporate ecosystem and environmental complexity into modeling and assessment stewardships. Predicting marine fish production from the changing physical conditions is an important contemporary demand to allow future projections and secure food production. However, fisheries assessment is generally based on deterministic models that lack realistic physical processes despite their importance to properly reproduce population dynamics. Intricate and convoluted physical and biological processes shape fish recruitment, which is the pivotal ecological cornerstone in fish population dynamics. Here, we use a large metapopulation of a harvested species managed across transnational boundaries in the northwestern Mediterranean, the European hake, to model recruitment dynamics in terms of physics-dependent drivers: larval dispersion and retention, and climate influence on early life stages survival. For different subpopulations, we develop multi-annual connectivity indices as larval transport, retention and self-recruitment obtained with a hydrodynamic model, as well as a proxy of the regional hydroclimate influencing early life stages survival. We then determine the relative influence of the regional circulation and the hydroclimate as selective forces affecting recruitment and survival across current management units. We evidence that fish recruitment in the northwestern Mediterranean can be reproduced by integrating connectivity estimates derived from ocean circulation models and the spatial dependence of hydroclimatic influences. This study opens new and broad opportunities to improve fisheries management by including short-term projections of physical oceanography, particularly in populations with complex spatial structures.



**June 6, 16:20/S10-Oral-13029**

**Vulnerability and adaptation of fishing communities to climate-driven species range shifts: Consequences for climate-ready management**

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Shifts in species distributions driven by warming oceans have the potential to disrupt the provision of ecosystem services to coastal communities. We coupled information on species distributions with fishing records to quantify the vulnerability and response of fishing communities to climate-driven shifts. We find that fishing communities varied widely in their exposure and vulnerability to shifting species distributions. In the California Current, available biomass of most target species to ports was stable over time. However, Pacific hake and Dover sole exhibited large magnitude swings in biomass and location along the coast. Northern ports most dependent on Pacific hake experienced the greatest fluctuations in available biomass due to their position in the range. Within the Northeast US, available biomass of many target species to ports changed more directionally over time. As lobster stocks in Southern New England collapsed, trap fishers that switched to crab maintained catches while those that continued to specialize on lobster suffered declines. Generalist trawl fishers were more broadly successful in exploiting southern species arriving in fishing grounds, particularly in the Mid-Atlantic Bight with high species turnover. In contrast, fluke-dependent trawlers near the species' southern range limit tracked their target northward more than 400 km to maintain this economically important catch. These results suggest catch diversity and economic value interacts with gear type and position within a species range to drive responses to shifting species distributions. Current regulations based on historical landings may need to be made more flexible to allow for this adaptation and ensure climate-ready management.

**June 6, 16:40/S10-Oral-12778**

**Current state and future scenarios for trans-boundary fisheries management in changing oceans of Canada and United States**

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Climate change is driving shifts in distribution of fish stocks towards areas with cooler environment, generally in higher latitude or deeper water. Particularly, distribution shifts in fish stocks that straddle between national jurisdictions or Exclusive Economic Zones (EEZ) are challenging transboundary fisheries management. Canada and USA share numerous economically and culturally important fish stocks in both the Pacific and Atlantic coasts. In this paper, we examine the past and projected future sharing of catches of transboundary fish stocks between the EEZs of Canada and USA. Firstly, we examine historical fisheries catches of fish stocks that straddle Canadian and USA EEZs from 1950 to 2010. Catches are divided by four sub-regions: Canada (Pacific), Canada (Atlantic), USA (Washington to Alaska), and USA (Atlantic). We then calculate the ratio of sub-regional catches (hereafter called stock-share ratio) between Canada and USA in the Pacific and Atlantic coasts and show that the stock-share ratio of some fish stocks such as Pacific salmon and halibut are changing in the direction as expected from the effects of ocean warming. Secondly, we analyze projections of changes in potential catch of these fish stocks under climate change from multiple earth system and species distribution models by the mid- to end of the 21<sup>st</sup> century. We calculate the projected stock-share ratio between Canada and USA under high and low greenhouse gas emission scenarios. These results highlight fish stocks and sub-regions that are most exposed to climate change impacts caused by shifting fish distributions and, consequently, the disturbance to transboundary fisheries management.

**June 6, 17:00/S10-Oral-12666**

### **Institutional settings, climate change and the re-distribution of tropical tuna fisheries**

Iratxe **Rubio**<sup>1,2</sup>, Unai Ganzedo<sup>3</sup>, Alistair Hobday<sup>4</sup> and Elena Ojea<sup>1</sup>

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There is broad evidence of climate change causing shifts in fish distribution worldwide, but less is known on the response of fisheries to these changes. Responses to climate driven shifts in a fishery may be very dependent and limited by the existing management and institutional arrangements. At the same time, these institutional settings can target different levels including stocks, fishers, fleets or nations, having a range of positive and negative effects to adaptation. In order to understand to what extent fisheries have adapted to climate change, we study international fleets targeting tropical tunas in the Atlantic Ocean using data from 1970 to 2015. These data include Skipjack, Bigeye and Yellowfin tuna catches from longliners, purse seiners and bait boats published by the International Commission for the Conservation of Atlantic Tunas. A spatiotemporal analysis is conducted to understand the change in the center of gravity of the fishery, the impacts of climate change variables through EOFs and GAMs, and the timeline of institutional arrangements including bilateral agreements and agreed quotas. We explore to what extent the shifts observed for the fleets and species catches are related to climate and institutional effects, by looking at the fishing countries and the Economic Exclusive Zones. As a result we derive policy implications for tropical tuna catches distribution shifts and international agreements that will help adaptation in the future.

**June 6, 17:20/S10-Oral-13084**

### **Scenario planning as a tool in protected species management and conservation in a changing climate: An Atlantic salmon pilot**

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Scenario planning is a process that embraces uncertainty and explores plausible alternative future conditions under different assumptions to help manage risk and prioritize actions. It has been used by a variety of organizations as a way to explore and help prepare for the future, lends itself well to exploring the uncertainty surrounding changing environmental conditions, and is widely applicable to natural resource management issues including species and habitat conservation programs. Within NOAA, scenario planning has been conducted by the Greater Farallones National Marine Sanctuary for ocean climate adaptation along the North-Central California Coast. Recently, this process was piloted by NOAA Fisheries to explore what the agency can do to improve Atlantic salmon (*Salmo salar*) resilience to changing conditions in both riverine and marine environments across its current range. Here, we will report out on the first use of scenario planning by NOAA Fisheries, highlighting the process, some outcomes from this pilot, and its applicability to marine conservation-climate change issues.

**June 6, 17:40/S10-Oral-13151**

**Fish on the move: Tools to support EBFM in facing challenges associated with species range shifts**

Tessa B. **Francis**

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One major response of marine species to changing ocean conditions is range shifts, resulting in novel species distributions and communities. Changes to the availability of commercially fished species in space has already presented challenges for the governance system, especially related to issues of allocation, but for other fisheries management decisions as well. How to account for cross-boundary social and ecological dynamics, at either the state or national level? There are additional social challenges presented by how fishers respond to changing species distributions, as questions of equity and access are associated with fisher and fishery mobility and adaptive capacity. What tools are available to support EBFM, and especially decisions related to the distribution of fisheries-related benefits in social-ecological systems, given the reality of changing environments and associated shifts in species distribution? This talk will offer advice, drawing on three examples:

- 1) Pacific sardine, where the impacts of the harvest control rules of three different countries' fisheries are evaluated for species whose distribution across borders varies with environmental conditions.
- 2) Pacific herring, where traditional and local knowledge is used to inform assessment of the impacts of fishing on the distribution of benefits at local and regional scales, and for mobile and non-mobile fishers.
- 3) Pacific herring, where we evaluate the performance of stock assessment models using fisheries data collected on a spatial scale not reflective of the spatial scale of the stock.

**June 6, 18:00/S10-Oral-13156**

**Addressing the challenge of climate change and fisheries: A framework for implementing climate-appropriate fishery management**

Merrick **Burden**, Kristin Kleisner, Rod Fujita, Doug Rader and Andrew Hutson

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Recent research suggests the human response to climate change could be the single largest factor determining the fate of marine fisheries. Climate change will drive changes to fish stocks in ways that will challenge existing fishery management systems. The failure to adequately adapt fishery management systems in ways that account for these changes will lead to a deterioration in management system effectiveness, depleted stocks, and adverse consequences to fishery-dependent communities and industries. The question is, how do we adapt and modify fishery management institutions in ways that are sufficient to address climate-related challenges? The challenge is nothing short of immense given the multi-faceted changes that will occur and the degree of uncertainty about what the future holds in store. Yet there are clear steps that can be taken that greatly increase the chances for transitioning fisheries in ways that make them climate ready. We discuss a framework for the implementation of climate-appropriate fishery management systems. This framework can be described as a systematic process with three major elements: 1) implementing tools that we know are responsive to climate change effects, 2) prioritization of scientific research on matters that we can identify but are uncertain about how to address, and 3) adaptive processes for dealing with the significant degree of risk and uncertainty associated with climate change.

## **S11: Benthic and pelagic system responses in a changing ocean: From genes to ecosystem level functioning**

**June 7, 11:10/S11-Invited-12727**

### **The effects of climate change on the ocean's plankton**

Ulrich **Sommer**<sup>1</sup>, Evangelia Charalampous<sup>1</sup> and Maria Moustaka-Gouni<sup>2</sup>

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Marine phytoplankton accounts for ca. 50% of global primary production. It provides the nutritional basis of fish production, removes CO<sub>2</sub> via the biological carbon pump and can have severe impacts on the recreational value of the sea through harmful algal blooms (HABs). The increase of greenhouse gas emission is expected to increase sea surface temperatures by 2–6°C until the end of the century, decrease p by 0.3–0.4 sincrease pH by 0.3 to 0.4 units, intensify vertical thermal stratification and reduce upwelling of deep water. The changes in the mixing regime will lead to a decreased nutrient supply to the surface waters, possibly with regional exception in coastal seas where nutrient supply is dominated by terrestrial runoff.

In the open ocean phytoplankton production and biomass are predicted to decrease in response to a decreased nutrient supply and increased grazing rates. Decreased nutrients and higher temperature will lead to smaller cell sizes. This change makes phytoplankton less available for mesozooplankton, thus diverts carbon flows towards the microbial loop, elongates the food chain towards fish and reduces the fish to phytoplankton production ratio. A higher in-situ respiration by the microbial food web will reduce the vertical export of carbon and reduce the efficiency of the carbon pump, while reduced planktonic calcification because of acidification might reduce this effect. In coastal seas, intensified stratification and steeper vertical nutrient gradients might foster HABs leading to fish kills and reduced water quality.

**June 7, 11:40/S11-Oral-12584**

### **Contribution of local adaptation to vulnerability of marine biota to warming**

Scott **Bennett**<sup>1</sup>, François Dufois<sup>2</sup>, Amanda Bates<sup>3</sup>, Graham J. Edgar<sup>4</sup>, Rick D. Stuart-Smith<sup>4</sup> and Thomas Wernberg<sup>5</sup>

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Global projections of the biological impacts of climate change have primarily considered that thermal niches remain constant across a species range, overlooking important variation in adaptive capacity among populations, with major implications for predicting warming vulnerability. Here we estimate warming vulnerability for coastal marine communities across the globe, capturing the full spectrum of local physiological adaptability that may exist among species within a community. We identify several global hot-spots and safe-spots of climate change vulnerability for marine communities and highlight many coastal areas where populations with locally-adapted and conserved thermal niches display stark differences in climate change vulnerability. These findings highlight important variation in warming vulnerability within and among biological communities, enhancing our capacity to anticipate climate change impacts and identify areas of management priority from local to global scales.

June 7, 12:00/S11-Oral-12355

### Short term CO<sub>2</sub> enrichment increases carbon metabolism of air-exposed intertidal seagrass communities

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Here we assess the short-term effects of CO<sub>2</sub> on the light responses of the net community production (NCP) and community respiration (CR) of intertidal *Z. noltei* and unvegetated sediment communities (consisting of microphytobenthos) of Ria Formosa lagoon, when exposed to air. NCP and CR were measured in-situ in summer and winter, under present and CO<sub>2</sub> enriched conditions using benthic chambers. Within chamber CO<sub>2</sub> evolution measurements were carried out by series of short-term incubations (30 min) using an infra-red gas analyser. Linear regression models fitted to the NCP-irradiance responses were used to estimate the seasonal budgets of air-exposed, intertidal production as determined by the daily and seasonal variation of incident photosynthetic active radiation (PAR). NCP of *Z. noltei* and unvegetated communities were higher under CO<sub>2</sub> enriched conditions in both summer and winter seasons and CR was lower, exceptions were CR of sediment communities in winter which was higher than NCP. The light compensation point (light intensity where production is higher than respiration) of *Z. noltei* and sediment community were lower in both seasons under CO<sub>2</sub> enriched conditions. Seasonal budget of community production was higher in *Z. noltei* than sediment communities. CO<sub>2</sub> enrichment can increase the intertidal community production during exposed condition and can have a positive effect on the carbon metabolism of intertidal photosynthetic communities in future scenarios of elevated atmospheric CO<sub>2</sub> levels

June 7, 12:20/S11-Oral-12655

### Climate vulnerability of marine fish, response traits and mechanisms

Olav Sigurd **Kjesbu**<sup>1</sup>, Anne Britt Sandø<sup>1</sup>, Mari Skuggedal Myksvoll<sup>1</sup>, Geir Ottersen<sup>2</sup>, Frode Vikebø<sup>1</sup>, Bridie Allan<sup>1</sup>, Maria Fossheim<sup>3</sup>, Geir Huse<sup>1</sup> and Svein Sundby<sup>1</sup>

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Anthropogenic driven climate change is predicted to affect the global oceans, with varying consequences for marine species, ecosystems and their function. Moreover, a series of underlying indirect effects have the potential to be additionally highly influential but less clear. At the fundamental level, climate-induced physiological stress may cause changes in bioenergetics that erode the capacity of marine animals to adapt to climate change, while accumulated changes in system productivity and predator-prey interactions can lead to alterations in food-web dynamics as well be linked to major changes in species geographical distributions. Hence, extrapolations based on single responses may lead to incorrect predictions about future impacts. However, understanding the consequences of climate change on marine populations given the complexities of interacting direct and indirect effects is highly challenging. This picture is further complicated by the varying sensitivities of local species across latitudes and waters. Nevertheless, by focusing on response traits (*i.e.* traits that determine whether and how an individual or a population is affected (with regard to fitness) by an environmental stressor), we provide a quantitative framework on the risks of climate change for marine species by addressing a number of commercially and/or ecologically important teleosts from equatorial to high latitude waters (coral trout, barramundi, anchovies/sardines, herring and cod). Using this integrative, step-wise approach, we may be better able to predict which of these marine species have the potential for acclimation, adaptation, range expansion and resilience. Following further advancements, this framework might have broad scale applicability to other species under climate change.

**June 7, 14:00/S11-Oral-12915**

### **Camouflage under climate change: Will marine species respond well to warming?**

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There is mounting evidence that temperature strongly affects the trophic relationships and interactions between predators and their prey, particularly in marine systems. Understanding how ocean warming will alter these thermally-dependent relationships is key to understanding the long-term impacts of climate change on marine ecosystems. While many studies have explored the impacts of warming on escape behaviour, little consideration has been given to how different prey species evade predator detection in the first place. Camouflage represents the first line of defence against being eaten, with many species capable of adjusting their coloration to better match their habitat. We investigated how seawater temperature influenced camouflage development in two intertidal crustaceans (*Carcinus maenas* and *Hyppolyte varians*). Placing individuals on different backgrounds and photographing them regularly enabled us to monitor their colour change over time, across a range of temperatures. The images were mapped to predator vision to determine how well camouflaged individuals were. Our results illustrate that these species are remarkably resistant to ocean warming, capable of developing optimal camouflage even under conditions predicted for the end of the century. The speed at which this camouflage was achieved varied with seawater temperature. By accelerating rates of colour change ocean warming may increase an organism's ability to camouflage, thereby reducing its predation risk. Our results demonstrate that, in addition to directly impacting the physiology of individuals, ocean warming will alter the ecological interactions between predators and their prey, further exacerbating the impacts of climate change on the structure and function of marine ecosystems.

**June 7, 14:20/S11-Oral-12684**

### **Effect of climate change on the distribution of global marine biodiversity**

Gabriel **Reygondeau**, Colette Wabnitz and William W. L. Cheung

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Marine biodiversity, defined as the number of species in a system, shapes the structure and the functioning of ecosystems that provide crucial services such as food provision to human populations. In a context of climate change, the oceans have absorbed 93% of the heat from climate change altering the natural environmental state of global marine ecosystems. Since, most marine organisms are ectotherms and hence have their physiology and distribution dependent on environmental forcing, a global shift of distribution of plankton to fish organisms has already been reported. While several studies have provided potential projection of global or regional change in distribution for macrofauna or exploited species using earth system models, few studies have attempted to provide a holistic projection of the effect of climate change on the distribution of marine species. Here, we assemble a global multi-taxonomic dataset, including 51 million records for 43,175 extant marine species ranging from phytoplankton to marine mammals, to model the present and future distribution of biodiversity. We used an ensemble environmental niche modeling procedure to project the distribution from 1950 to 2100 of all species gathered according to 2 representative concentration pathways and 3 earth system models. Results from the study provided a comprehensive impact of anthropogenic climate change on marine biodiversity that can be subdivided by habitat (benthic, pelagic, coastal, open ocean) or trophic level.

**Keywords:** Biodiversity, Environmental niche model, Ensemble model, Global Ocean, Climate change

**June 7, 14:40/S11-Oral-12766**

## **Effect of ocean acidification on Antarctic marine bacterial, archaeal and eukaryotic communities**

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Near-shore Antarctic microbes are the drivers of productivity, elemental cycling and effect ocean biogeochemistry yet little is known about their response to ocean acidification, despite Antarctic waters being amongst the most vulnerable to increased CO<sub>2</sub> levels in the world. A six-level ocean acidification experiment was conducted on a natural microbial community at Prydz Bay, East Antarctica using minicosm techniques. The MiSeq Illumina platform was used to investigate the effect of ocean acidification on the bacteria, archaea and eukaryotes within minicosm communities. No significant effect of CO<sub>2</sub>-driven ocean acidification was seen on the bacterial and archaeal community despite having overall higher abundances in the higher CO<sub>2</sub> treatments. This suggests that ocean acidification may indirectly affect bacteria and archaea through their interactions with other microbes within the community. The eukaryotic community, however, showed a shift in community composition, with high CO<sub>2</sub> levels favouring small cells. This suggests that in the future, ocean acidification will alter the eukaryotic community composition and microbial interactions, and therefore impacting the ecosystem services these communities provide. The flow on effects of such changes could have significant consequences for the near-shore Antarctic food web and elemental cycling if anthropogenic CO<sub>2</sub> release continues unabated.

**June 7, 15:00/S11-Oral-12776**

## **The sensitivity of climate-induced shifts in the distribution of reef fish to the presence of reef habitat**

Ravi R. **Maharaj**<sup>1</sup>, Gabriel Reygondeau<sup>1,2</sup> and William W. L. Cheung<sup>1,2</sup>

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At the global scale, the distribution of commercially important fish species has displayed significant changes in recent times, attributed mainly to the relation between changes in ocean temperature and the oxygen-limitation on fish metabolism. At smaller spatial scales another set of factors, such as the distribution of habitat resources, become more influential in structuring fish communities, particularly those associated with tropical coral reefs. Corals, the primary habitat building organisms in tropical coastal biomes, have shown a high sensitivity to changes in the physical marine environment. Declines in live coral cover are expected to be followed by future declines in the architectural complexity and overall quality of reef habitat. In addition, different species of reef fish rely to varying degrees upon reef habitat, which may play into the importance of habitat loss for distribution shifts across species assemblages. In this study, we model the potential effects of climate change on reef fish communities at the regional scale through direct climate forcing on species distribution, as well as indirect effects of habitat loss due to bleaching to determine the relative role of coral decline on potential species shifts. Using the Caribbean Large Marine Ecosystem as a case study, we employ three prominent species distribution models, specifically Boosted Regression Trees, Maxent and Artificial Neural Networks, to develop scenarios of fish species distribution across different national EEZs, representing two emission concentration pathways as well as the presence and absence of coral habitat weighted by its importance to different species. The findings of this study will add to a growing body of literature that explores the importance of habitat to mitigating the impacts of climate change on global marine biodiversity with additional the aim of informing the development of management policy for Caribbean fisheries resources.

**June 7, 15:20/S11-Oral-12626**

## **Structural and Functional changes of multi-trophic communities in a large marine ecosystem**

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Community composition is often studied on single organism groups and calculated based on species abundances, while it is increasingly recognized that species characteristics, rather than their identity serve to promote ecosystem functions and services. Here, we investigated temporal changes in taxonomic and functional composition of multi-trophic communities across sub-regions of the Baltic Sea, characterized by pronounced differences in species richness and environmental conditions. Using multivariate time-series analysis, we studied the principal dynamics and trends in the structural (abundance) and functional (trait) composition across taxa and sub-regions and linked them to environmental and anthropogenic changes. Our multi-trophic analysis spans benthic invertebrates and fish, as well as phytoplankton, zooplankton and planktivorous fish, hence enabling a comparison of trends and drivers across benthic and pelagic habitats. Preliminary results show a consistent structural reorganization in species composition across sub-regions and taxa in the late 1980's and 2000's. However, the corresponding trends and dynamics in the trait composition were more variable across regions and taxa, hence indicating that structural reorganization are not always accompanied by functional changes. The main identified drivers of community composition in the Baltic Sea were salinity, oxygen and temperature, which are expected to change further under ongoing Climate Change. In light of these results we argue that a multi-trophic approach including both structural and functional composition could help moving towards a holistic understanding, assessment and management of marine ecosystems in the face of change.

**June 7, 15:40/S11-Oral-12816**

## **Temperature effects on the transfers of biomass in marine food webs**

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Temperature affects metabolism of individual organisms and, consequently, the flow of energy or biomass across marine food web. Different characteristics and species composition of marine ecosystems should result in different sensitivity of biomass flows to warming. Here, using a trophodynamic approach and, global fisheries catches and life history traits of marine species, we examined temperature effects on two characteristics of biomass transfer in a wide range of coastal marine ecosystems. Within each cell (1×1) in the coastal biomes of the world Ocean, we estimated the yearly values of two trophic indicators: (1) the Partial Trophic Efficiency Cumulated Indicator (PTE) that represents the fraction of biomass or energy transfers from one trophic level to the next by predation, and (2) the Time Cumulated Indicator (TCI) that indicates the residence time of the biomass in the food web. We tested the relationship between Sea Surface Temperature (SST) and the PTE and TCI in each coastal biome using a generalized linear model. We also explored a hypothesis that temperature effects on biomass flows (as indicated by PTE and TCI) are shaped by the life history strategies of the dominant species. We used the ratio of the von Bertalanffy growth parameter K to asymptotic length to represent species' life history strategies. The findings suggest that warmer oceans are likely to result in faster and more efficient biomass flows, while such temperature effect on PTE is higher in polar and temperate ecosystems that are dominated by species with long-lived, slow growing life history strategies.



**June 7, 16:20/S11-Oral-12617**

**The effects of climate change on ground fish communities' diversity and functions in a tropical context: The case of the continental shelf off French Guiana**

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For more than two decades, describing and understanding the spatio-temporal dynamics of fish communities has been subject to increasing attention from scientists and fisheries managers. Such dynamics are crucial for ecosystem functioning and productivity which provide goods and ecosystem services. Most of the works based on fishing and climate change effects on fish communities' ecology and functions are focused mainly on temperate and boreal ecosystems. There is a lack of information concerning the adaptation capacity of the fish communities to warmer waters in tropical regions. Our study is based on datasets from surveys conducted from 1993 to 2017 using a bottom shrimp trawl between 10 and 60m depth in a tropical continental shelf (French Guiana) which is characterized by a significant increasing of SST and a declining fishing pressure. We firstly compared the functional richness of the fish communities to values obtained from a null model that enabled us to identify the relative importance of the assembly rules (niche filtering hypothesis versus limiting similarity hypothesis) using a trait-based approach. Then we analyzed the ground fish communities' spatio-temporal structure and functional diversity. Subtropical species occurring at the upper limit of their thermal range are disfavored with warming waters provoking potential changes in the fish communities' structure. Moreover, individual observed sizes were larger in the recent years probably due to the decrease of the fishing pressure. The consequences of such alterations are discussed.

**June 7, 16:40/S11-Oral-12898**

**Local acidification caused by coral-algal phase shifts exacerbates the effects of global ocean acidification on tropical reefs**

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Global and local stressors acting simultaneously on coral reefs give turf and macroalgae a competitive advantage over reef-building corals. Such phase shifts often foster a high production of labile dissolved organic matter (DOM) released by algae. This material may be readily remineralized to CO<sub>2</sub> by microbes. These potential interrelationships, however, have not been investigated yet. Thus, we measured oxygen (O<sub>2</sub>) and DOM fluxes, along with changes in the carbonate chemistry in both coral- and algae-dominated communities (4 replicates per treatment), using novel in-situ incubation chambers and sensors deployed bi-monthly on nearshore reefs of the Central Red Sea during one year (7 sampling periods). Findings revealed moderate fluctuations of O<sub>2</sub> concentrations (down to 60% saturation) and maximum pH drops of 0.2 units in the adjacent water column of coral-dominated communities, with no seasonal effects. Contrary, algal dominance was associated with the development of nighttime hypoxia (down to 25% O<sub>2</sub> saturation) and increased acidity (pH drops of >0.4 units). These extreme values were linked to highest water temperatures in summer. Significant positive correlation between pH and both O<sub>2</sub> and DOM concentrations occurred. This supports the hypothesis that microbial remineralization of labile reef algae-derived DOM may cause local acidification. Data simulation reveals synergistic effects of such local reef acidification and global ocean acidification under predicted IPCC scenarios. The microbe-mediated release of CO<sub>2</sub> during algae-derived DOM mineralization, more frequent heating events, and ensuing shifts in the carbonate system may create a negative feedback loop that compromises the reversal of coral-algal phase shifts.

June 7, 17:00/S11-Oral-13001

### Early perspective: A 3D approach to the effects of elevated CO<sub>2</sub> in the neuroanatomic development of an oviparous shark

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As atmospheric CO<sub>2</sub> levels rise, continuous uptake by the oceans is changing the seawater chemistry, resulting in ocean acidification (OA). The direct impacts of ocean acidification in elasmobranch fishes have only recently been addressed and behavioral disruption appears as a major concern. Nonetheless, effects over their brain structure and development have never been assessed. Here we investigate the impacts of OA in the early neuroanatomy and relative brain development rate of temperate shark embryos (*Scyliorhinus canicula*) exposed to high CO<sub>2</sub> conditions (900  $\mu$ atm |  $\Delta$  0.3 pH units) since laid. Using open-source Optical Projection Tomography (OPT) technology to build three-dimensional models of the neuroanatomy of six major areas [olfactory bulbs, telencephalon, diencephalon, mesencephalon, cerebellum, and medulla oblongata] we follow the brain development patterns across the embryogenesis. Preliminary results with a tropical catshark (*Chiloscyllium plagiosum*) suggest potential alterations in the relative size of the optic lobe following post-hatch exposure to high-CO<sub>2</sub> conditions, with probable consequences in the processing and integration of visual information and thus, the ability to properly respond to environmental cues. Moreover, recent research by our team found differences in the relative brain region size after exposure to high-CO<sub>2</sub> levels in juvenile teleost fishes, reporting species-specific patterns. Sharks have a crucial role in the balance of the oceans trophic ecology and the population decline seen in recent years may result in a top-down disruption of marine ecosystems. OA may present itself as an additional threat to this k-strategy predator, particularly if undermining the brain-power of the new recruits.

June 7, 17:20/S11-Oral-13148

### Cognitive and neurobiological disruption of cleaning mutualisms under ocean acidification and warming

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Cleaning mutualisms are the textbook example of animal cooperation. On coral reefs, the iconic cleaning relationship between cleaner fish and their clients is essential for maintaining community diversity and abundance. However, cleaners can choose to collaborate or cheat, as they prefer eating mucus from their clients where possible. Cleaners are known for their remarkable cognitive abilities and sophisticated behavior, that they use for manipulation, partner control and tactical deception of their partners. However, the ecological conditions where cleaners were able to evolve their cognitive abilities are changing due to human-induced environmental changes. Here we show that acclimation to ocean acidification and warming conditions decreased cleaning motivation and the quality of interactions between cleaners and clients. Moreover, using a well-known cognitive task derived from the biological market theory, we observed a substantial impairment in cleaner wrasse cognition abilities when exposed to elevated CO<sub>2</sub>. At the molecular level, dopamine, serotonin and norepinephrine concentrations (and respective turnovers) were significantly affected by these stressors. Elevated CO<sub>2</sub> interacted with dopamine impairing the cleaners' and clients' perception and with serotonin and norepinephrine modulating motivation for interaction. On the other hand, warming affected synaptic activity in both mutualist partners. We advocate that the breakdown of cleaning mutualisms will affect the maintenance of local community structures on coral reefs.

June 7, 17:40/S11-Oral-13135

### Complex life cycles and complicated responses to change

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Abiotic conditions in many near-shore marine environments are highly variable. Particularly along temperate coastlines, temperature, salinity, and oxygen levels can swing dramatically over daily and seasonal cycles. The organisms that live in these environments are often able to cope with these changes through phenotypic plasticity and buffering behaviors that allow persistence and growth across a wide range of conditions. Such durability has offered hope that these organisms will be able to adjust as the ocean changes. However, a deeper look into the effects of abiotic variation suggest that the appearance of broad tolerance and large species ranges may mask signatures of local adaptation, local differentiation, and plasticity that is tuned to specific patterns of environmental variation.

To understand the interaction of genetic and plastic variation in responding to novel and fluctuation conditions, we have been working with two widespread species with reputations for remarkable tolerance, a sea anemone (*Diadumene lineata*) and a red alga (*Gracilaria vermiculophylla*). In both cases, incorporating data from across the life cycle reveals that small changes in abiotic conditions have the potential to dramatically alter patterns of growth, reproduction, and genetic structure. Together, these species show us that making good predictions about the future of marine organisms is going to require broader consideration of the interaction of global change with the diverse and complex life cycles found in the ocean.

June 7, 18:00/S11-Oral-12862

### Krill in a changing environment: Leveraging multiple approaches to understand a complex organism

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Krill are ecologically important zooplankton but challenging to monitor because they have complex behaviors, their populations are highly variable in space and time, and they are strongly affected by both bottom-up and top-down controls. They are abundant in upwelling systems and undergo large diel vertical migrations; thus, they are often exposed to a wide range of  $p\text{CO}_2$ ,  $p\text{O}_2$ , and temperature conditions on daily and seasonal time scales. Despite this, laboratory tests on several species of krill have indicated that they may be more sensitive to increased  $p\text{CO}_2$  than other crustacean zooplankton. These results signal that krill may be living close to their tolerance limits, or, the variability observed among individuals in experiments and their persistence in dynamic environments indicate that complex factors in the field mask the responses observed in the laboratory. Puget Sound (PS) is a large estuary with broad spatial variations in oxygen and pH that can be used as analogues for expected future changes. Laboratory tests show that the most abundant krill species in PS, *Euphausia pacifica*, is sensitive to pH levels they already experience in some areas, yet krill populations persist there. We investigated the use of enzyme activities as *in situ* indicators of *E. pacifica* physiology across a gradient of oxygen and pH conditions in PS, paired with traditional shipboard incubations, laboratory exposure experiments, and field distribution observations. I will synthesize what is known about *E. pacifica* and discuss how multiple methodologies can be leveraged to understand complex pelagic species in changing environments.

**June 8, 10:40/S11-Oral-12881**

**Resistance of subtidal reefs to change under future conditions: The role of benthic grazers**

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Future elevated CO<sub>2</sub> and temperatures are expected to increase primary productivity across tropical marine habitats, creating a potential for a shift to algal dominated systems. The negative impact of these stressors in this way has been shown to be alleviated by the increased consumption rate of benthic grazers; a potential compensatory mechanism preventing a regime shift. Importantly, the strength of consumption is regulated by the metabolic demands of the grazers, which is expected to increase in line with warming until a threshold is crossed, at which biological processes can no longer be maintained. Indeed, tropical marine species are generally considered to be more susceptible to ocean warming because they live closer to their thermal tolerance limits than colder-water species. Here, I determined the short-term acclimation potential of important grazing sea urchin and gastropod species on Hong Kong subtidal reefs; how metabolic and consumption rates alter under predicted CO<sub>2</sub> and temperature conditions. An apparent mismatch between metabolic rate and grazing rate was found for both species. Urchin metabolic rate was higher at future temperatures, but grazing rate was depressed. In contrast, CO<sub>2</sub> and temperature caused a decrease in gastropod metabolic rate and feeding, suggesting reduced ability to acclimate to this stressor compared to the sea urchins. These results suggest that different taxa may be differentially affected by environmental conditions and that the strength of compensatory response could be dependent on functional redundancy in grazer communities.

**June 8, 11:00/S11-Oral-12933**

**Relative depth constraints on temperature-induced range shifts for continental shelf species**

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In response to increasing ocean temperatures marine species on the continental shelf are shifting their ranges towards the poles or into deeper depths to stay at their optimal temperature. It is important to quantify what habitat limitations species will face as they make these range shifts. Global bathymetry data was analyzed to identify areas where species will experience habitat bottlenecks or expansions if they make predicted range shifts. It is commonly thought that there is more available habitat at deeper depths on the continental shelf. However, the total amount of area at specified depth bands varied widely by Large Marine Ecosystem (LME), so some species will see a reduction in available habitat when they try to move into deeper depth bands. Similarly, area at depth is not uniform along continental shelves. In some regions area on the continental shelf is concentrated in only one latitudinal band, with little area anywhere else. In every LME group, there are latitudes where the continental shelf narrows and causes a sharp reduction in territory for species shifting their ranges latitudinally. For example, the Gulf of Maine is a habitat bottleneck for species off of the East Coast in the United States. But, if species can get around the Gulf of Maine they gain access to significantly more habitat than before. Identification of places where there are habitat bottlenecks or habitat expansions on the continental shelf can inform predictions about the impact of climate change on the abundance of marine species.

June 8, 11:20/S11-Oral-12901

## Variability of the spatiotemporal distribution of yellowfin tuna and its response to environmental change in the eastern Pacific Ocean

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Yellowfin tuna (YFT), *Thunnus albacares*, is a commercially important species in the Pacific Ocean with catch more than 400,000 Mt/year all over the world. YFT is vulnerable to environmental changes under global warming, showed an active high catch status inversely with other species of tunas and brings a potential shift to the climate variations. Catch of YFT shows homogeneous high frequency fluctuations on the ENSO transitional phases. However, the mechanism of environmental processes associated with ENSO that affected variations of YFT was not understood well and the stock risk is underestimated. In order to detect the characteristics of the catch variations of YFT in the eastern Pacific, an integrated database from Argos to remote sensing data was established, and the fishery data (1994-2012) of 1° spatial grid were analyzed with environment factors (SST, SSH, Chl-a, SSW) in the eastern Pacific Ocean (19.5°S~33.5°N, 71.5°W~149.5°W). The Morlet wavelet analysis and Empirical Orthogonal Function (EOF) analysis were used to identify the spatiotemporal modes, and generalized additive models (GAMs) were applied to investigate the hotspots of YFT and to predict its future pattern. The results showed that there were oscillations with a gradually reduced period between 2-6 years in the time series data of catch while the first two EOFs confirmed that the main distribution of YFT have related to the seasonal variation signals (especially JJA and DJF) and it led to fragmentation. These findings were made into a risk assessment index model of YFT which gives an additional insight into resource prediction and management accordingly.

June 8, 11:40/S11-Oral-13041

## The story so far: An *in situ* pairing of chemical oceanography and physiology

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Climate change is a pressing environmental concern, and understanding how abiotic variation contributes to population dynamics and persistence may ultimately predict the fates of species. Ocean acidification negatively impacts a range of species, including those using calcium carbonate for shell formation such as shellfish, which are important as ecosystem engineers and for food security. While much is known about carbonate chemistry and impacts of ocean acidification on the U.S. Pacific coast, there is limited regional information in British Columbia (BC), especially in socio-economically important coastal zones for aquaculture and migrating fisheries populations. Laboratory experimentation mimicking future climate scenarios provide valuable information on biological impacts under controlled conditions, but do not take into account the natural environmental fluctuations of coastal environments that may influence population persistence. This research program combines lower trophic level monitoring (plankton analysis), physiological responses (functional genomics of commercial bivalves) and high speed near real-time oceanographic monitoring at a field site in the northern Salish Sea, to provide information on system variability and its biological impacts on coastal ecosystems. Site abiotic variability will be discussed in the context of pre-industrial to current condition effects on species. Shellfish gene expression data will focus on population plasticity or microevolutionary adaptation to seasonal, optimal and sub-optimal calcium carbonate conditions over the short and long-term.

**Keywords:** Climate change, ocean acidification, bivalve physiology, adaptation

**June 8, 12:00/S11-Oral-13165**

**Experimental methodologies optimized for examining multiple stressors, variable environments, and the scope of responses in early life-stages of marine fishes due to climate change**

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Studies of biological effects of climate change must progress from descriptive to predictive and from qualitative to quantitative characterizations of relationships between environmental drivers and biotic responses. We describe several experimental methodologies useful for climate-change studies to achieve quantitative, predictive depictions of biological responses. These methods provide broad-spectrum, high-frequency, and variable environmental treatment levels to characterize the plasticity of responses by small-bodied marine organisms. First, a thermal gradient block (TGB) is used to generate several dozen constant and variable thermal regimes for evaluating effects on key life-history processes. The second methodology, analogous to the TGB, uses a novel means of generating a high frequency (>20) of CO<sub>2</sub> environments that can be either constant or variable, and has proven useful for studying the scope of biological responses to ocean acidification. Both systems have been tested and demonstrated here using a set of biological responses exhibited by early life-stages of the estuarine forage fish Atlantic silverside (*Menidia menidia*). With respect to thermal regimes, embryonic period duration decreased as a power function with temperature, size at hatch decreased at warmer temperatures, and survival to hatch decreased at both temperature extremes. Elevated CO<sub>2</sub> resulted in decreased embryonic period duration, size at hatching was maximal at intermediate CO<sub>2</sub> concentrations, and survival decreased with CO<sub>2</sub> variability. Both methodologies can simulate high-frequency (*e.g.*, daily) temporal variability. Importantly, quantification of these biological responses is usually infeasible using low treatment frequency designs and, in some cases, the underlying shapes of the responses would not be revealed.

**June 8, 13:40/S11-Oral-12436**

**Is local adaptation driving the transcriptomics response to multiple stressors in the kelp *Saccharina latissima*?**

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Climate change is significantly impacting the structure and function of marine ecosystems worldwide with implications for species distribution ranges. In coastal systems, climate change may also alter other abiotic factors such as salinity, which may decrease due increased glacial melting in the Arctic or precipitation in temperate regions. Despite the prime ecological importance of kelps (order Laminariales) which dominate rocky benthic ecosystems in temperate to polar regions, the acclimation mechanisms and transcriptomic responses remain understudied. Here, we investigate the physiological and transcriptomic responses in sporophytes of the sugar kelp, *Saccharina latissima* to salinity stress after acclimation to temperature and their interrelationships. Juvenile sporophytes of a strain from Roscoff, France were pre-cultivated at 8°C and 30 PSU for three months. After seven days of acclimation to 0°C and 15°C, sporophytes were exposed to a low salinity treatment (20 PSU) for 24h. We established a reference transcriptome from all reads obtained through Illumina HiSeq. A total of 205 363 transcripts were assembled containing 135 959 “Trinity’s genes”. Gene expression is mostly driven by salinity stress than by temperature. The highest number of regulated genes, in comparison to the control, was found in response to the treatment 0°C low salinity (3003), followed by 8°C low salinity (1491) and 15°C low salinity (1158). Moreover, only few genes (168) were found to be differentially expressed in all low salinity treatments, showing that the response to low salinity is modulated by temperature. Growth, photosynthetic efficiency and pigment content were also impacted by stress.

**June 8, 14:00/S11-Oral-12746**

### **Effects of temperature increase and oxygen decrease on marine benthic invertebrates**

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Increased carbon dioxide emission increase temperature of not only atmosphere and but also seawater. Because of low dissolution of oxygen and increased biological activity, ocean warming entails deoxygenation or hypoxic problems in the seawater. We explored the combined effect of seawater warming and low dissolved oxygen (DO) on behavior and physiology of marine invertebrates such as Manila clams, Pacific abalone, and sea urchins. Under high temperature (23.5°C) and low DO (3mg/L) treatment, young Manila clams (*Venerupis philippinarum*) increased their emerging behavior and eventually had the highest mortality among different treatments. Interestingly, mortality under high temperature and high DO was higher than that under control temperature (20°C) and low DO. There was no significant difference in their oxygen consumption rates between treatments. In Pacific abalone (*Haliotis discus hannai*), increased temperature (23°C) had a positive effect on foraging behavior but decreased oxygen had a negative effect. In adult sea urchins (*Mesocentrotus nudus*), whereas there was no significant effect of temperature (22.5°C vs 18.5°C) and DO (6-7mg/L vs. 3.5 mg/L) on foraging and righting behavior, both warming and hypoxia had negative effects on food intake. Given all these results, temperature and DO have differential effects on invertebrates and tolerance to these stressors are different depending on species.

**June 8, 14:20/S11-Oral-12985**

### **The impact of ocean warming and acidification on the physiology of the seahorse *Hippocampus reidi***

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Seahorses are some of the ocean's most charismatic creatures and are considered as flagship species of the marine environment owing to the varied habitats they occupy (e.g. seagrasses, mangroves, coral reefs and estuaries). Unfortunately, their populations have been declining worldwide primarily because of habitat degradation and overexploitation. The unique characteristics of these organisms make them particularly sensitive and vulnerable to disturbance of their natural habitat, however, little is known about their capacity to tolerate future ocean conditions. Here we investigated a comprehensive set of biological responses of *Hippocampus reidi*, after 20 days exposure to future predictions of ocean warming (+3°C) and acidification ( $\Delta\text{pH}=0.5$ ). The impact of environmental warming and acidification in their early development, namely: i) growth; ii) survival; iii) malformation rates; iv) changes in element composition, calcium (Ca), magnesium (Mg) and phosphorous (P); and v) heat shock response and lipid peroxidation is discussed.

**June 8, 14:40/S11-Oral-13000**

**Seasonality of fouling organisms in view of climate change and bioinvasions**

Carolina **Bastidas** and Judith Pederson

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Increased seawater temperature, occurrence of diseases and northward extension of distributions of organisms are among factors likely altering the suite of physical and biological disturbances that create space on hard surfaces. This study examined the settlement of fouling organisms on artificial plates throughout a year to assess the role of open space and early competition on establishment and to compare patterns between two sites at different bioregions along the Northeast US coast. These locations were chosen because pre-existing data from five rapid assessment surveys between 2000 and 2013, allowed comparisons between deployed plates with *in situ* communities. Settlement of native and non-native species were recorded over 12 months using plates removed at one, two, and three months after submersion. We assessed settlement of organisms and interactions among species and compared these data based on location and previous surveys. Similar comparisons in fouling communities at other sites have shown that species composition has drastically changed over decadal time scales, favoring non-native species. We anticipated that non-native ascidians will be dominant in the developing fouling communities, with specific species likely varying throughout the year. We observed that a native species, *Ectopleura larynx* could dominate the plates for several months in one location but not the other, and when the population crashed, non-native ascidians successfully occupied subsequent open spaces. Changes in fouling settlement potentially linked to climate change are relevant to proposed aquaculture activities as study sites host non-native ascidians that have impacted mussel and oyster culture in the region.



## **S12: Scenarios and models to explore the future of marine coupled human-natural systems under climate change**

**June 4, 16:40/S12-Oral-12648**

### **Fisheries Management in an uncertain future: Using management strategy evaluation to assess robustness of harvest guidelines to changing North Pacific albacore tuna productivity and distribution**

Desiree **Tommasi**<sup>1</sup>, Barbara Muhling<sup>1</sup>, Steve Teo<sup>2</sup> and Gerard Di Nardo<sup>2</sup>

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Changes in ocean conditions are known to affect the productivity (recruitment, growth, survival) and distribution of many valuable marine fish, including highly migratory species like Albacore tuna (*Thunnus alalunga*). Both climate variability and change are expected to alter North Pacific Albacore tuna (NPALB) productivity and availability, with implications for fisheries management. To maintain resilience of the NPALB population under climate change and limit sociological and economics impacts, future fishery management advice needs to be robust to uncertainty in productivity and distribution. Here we outline a Management Strategy Evaluation (MSE) framework based on the Stock Synthesis software and designed to assess the consequences of uncertainty in NPALB productivity and distribution for achieving NPALB management objectives. Effectiveness in meeting predefined management objectives under shifting recruitment, time-varying growth, and time varying age-selectivity is compared across a range of harvest guidelines and reference points.

**June 4, 17:00/S12-Oral-12581**

### **Impacts of climate change on Pacific North America's small-scale fisheries**

Melanie **Ang**<sup>1</sup>, Ratana Chuenpagdee<sup>2</sup>, U. Rashid Sumaila<sup>1</sup> and William W. L. Cheung<sup>1</sup>

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Climate change will have significant implications for marine ecosystems and fisheries, however the ability of small-scale fisheries to cope with these impacts remain relatively unknown. Globally, small-scale fishers form 90% of total employment in the fishing industry. Yet, research and policies on small-scale fisheries are often marginalized by efforts that largely focus on industrial operations. Comprehensive understanding of small-scale fisheries under climate change will contribute positively to resource management, and consequently, help ensure sustainable livelihoods and food security. In this research, we compare the projected impacts of catch and species composition of small-scale fisheries to large scale fisheries in the Pacific North America region under the lower and upper climate change scenarios. By integrating fisheries catch data with the Dynamic Bioclimate Envelope Model under different climate emission scenarios, we project the spatial and temporal changes in catch amount and taxa composition. Our results indicate that large-scale fisheries will experience greater climate-induced benefits on catch potential and species richness compared to small-scale fisheries in the region. The findings suggest that the characteristics of small-scale fisheries, such as having higher diversity of exploited species and fishing gears, as well as lower fuel costs, may make them less sensitive to climate change impacts. These results help inform the importance of sustaining small-scale fisheries to improve adaptive capacity of fisheries management under climate change.

June 4, 17:20/S12-Oral-13093

### **Bioenergetic influence on the historical development and decline of industrial fisheries, and implications for a warming ocean**

Jérôme **Guiet**<sup>1</sup>, Daniele Bianchi<sup>2</sup>, William W. L. Cheung<sup>3</sup> and Eric D. Galbraith<sup>1</sup>

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In 35 of the 66 Large Marine Ecosystems of the world, a steady increase of wild fish harvest was followed by a peak and decline. The peaks generally occurred first in high latitudes and subsequently in low latitudes, and also showed more rapid rates of increase and decline at high latitudes. It might be expected that different economic, technological or regulatory conditions were the sole determinants of this regional variability. However, environmental factors may also have influenced these patterns. We focus on these factors through comparison with idealized simulations using a spatially-resolved bioeconomic model, forced by observed primary production and water temperature, and a steady globally-homogeneous increase in fishing technology. The model produces peaks of harvest because of the development and subsequent over-exploitation in the absence of fisheries regulation. Remarkably, the model produces a high- to low-latitude progression of fishing that is similar to observations. In simulations, this results from greater pristine biomass accumulation in cold waters, so that profitable fisheries develop at a lower level of fishing technology, earlier in time. Warm water ecosystems, with lower biomass, only become profitable later when fishing technology has improved. In warmer waters the replacement rate of harvested biomass is also faster, which slows the rate of fishery decline. Although these mechanisms can explain only part of the development of fisheries, we suggest that they played a significant role in the historical progression of the coupled human-natural system and should be considered to explore the future of marine ecosystems in a warming ocean.

June 4, 17:40/S12-12564

### **Factors affecting distribution of the Atlantic surfclam (*Spisula solidissima*), a continental shelf biomass dominant, during a period of climate change**

Eileen E. **Hofmann**<sup>1</sup>, Eric N. Powell<sup>2</sup>, John M. Klinck<sup>1</sup>, Daphne Munroe<sup>3</sup>, Roger Mann<sup>4</sup>, Dale B. Haidvogel<sup>5</sup>, Diego Narváez<sup>1,6</sup>, Xinzhong Zhang<sup>5</sup> and Kelsey Kuykendall<sup>2</sup>

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The Atlantic surfclam (*Spisula solidissima*) is a dominant member of the biological community of the Middle Atlantic Bight continental shelf and also a commercially harvested species. Climate warming is affecting the biology and distribution of this species, which provides an opportunity to investigate the processes and conditions that are restructuring this fishery and the implications for ecological and socio-economic systems. The Management Strategy Evaluation (MSE), which is a system of linked models, developed for the surfclam fishery is an attempt to provide a comprehensive mechanistic description of the surfclam's response to climate change and understand the cascade of effects initiated by changes in oceanographic conditions that ultimately appear as social and economic effects, which in turn inform development of management policies for the resource. This presentation provides an overview of the components of the surfclam MSE, relevant results, and implications for management and policy. The lessons learned from the surfclam MSE provide a basis for applying similar approaches to other ecologically important species that are also commercially exploitable resources.

**June 4, 18:00/S12-Oral-13075**

**Climate impacts on ecosystem productivity and fisheries management: The 2014 - 2016 Gulf of Alaska marine heat wave and the cod crisis that followed**

Steven **Barbeaux**, Kirstin Holsman and Stephani Zador

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In 2014-2016 an unprecedented warming event in the eastern North Pacific Ocean (“the Blob”) triggered changes in ecosystem productivity in the Gulf of Alaska (GOA) that ultimately impacted fisheries management. The marine heatwave was noteworthy in its geographical extent, depth range, and persistence, with evidence of shifts in species distribution and reduced productivity of lower-trophic and upper-trophic organisms. For example, in 2017 groundfish surveys indicated that GOA Pacific cod (*Gadus macrocephalus*) had experienced a greater than 70% decline in abundance from the previous survey in 2015. The GOA Pacific cod fishery supports a \$103 million dollar fishery, 29% of the total groundfish harvest in the GOA. In this study, we demonstrate that an increase in metabolic demand during this “endless summer” as well as a reduced prey supply can explain the decline in Pacific cod. Although increased mortality likely led to the decline in current fishable Pacific cod population, historically low recruitment concurrent with the heat wave portends a slow recovery for the stock and gives a preview of impacts facing this region due to projected climate change. We evaluate the intersection of climate change with ecosystem-based fisheries management in context of GOA Pacific cod with a description of the sensitivities of the ecosystem, how the Pacific cod single-species stock assessment model has been adapted, and an evaluation of the management system in the North Pacific, as well as suggestions on how this system could be improved and potentially implemented elsewhere.

**June 5, 11:00/S12-Invited-12780**

**Science for an uncertain future: Evaluating climate impacts and management approaches using a coupled modeling framework**

Kirstin **Holsman**<sup>1</sup>, Anne Hollowed<sup>1</sup>, Alan Haynie<sup>1</sup>, Albert Hermann<sup>2</sup>, Wei Cheng<sup>2</sup>, Kerim Aydin<sup>1</sup>, James Ianelli<sup>1</sup>, Stephen Kasperski<sup>1</sup>, André Punt<sup>3</sup>, Amanda Faig<sup>3</sup>, Jonathan Reum<sup>3</sup>, Thomas Wilderbuer<sup>1</sup> and William Stockhausen<sup>1</sup>

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Marine ecosystems face an unknown future. Interacting pressures, including those from climate variability and long-term change, present challenges while nascent resource management approaches and evolving technologies offer sustainable adaptive solutions. Consideration of these combined pressures and adaptive potentials in projection modeling can yield divergent, yet equally plausible future trajectories, which invariably reflect the relative strength of bottom-up, top-down, and density-dependent interactions. We demonstrate the importance of evaluating the sensitivity of projections to these controlling factors using a multi-model integrated framework as part of the Alaska Climate Integrated Modeling (ACLIM) project. This includes projecting the biomass and distribution of groundfish and invertebrate species in the Bering Sea, Alaska (USA) under 11 future climate trajectories with low to high carbon emissions, various assumptions regarding climate-recruitment relationships and trophic interactions, as well as multiple socioeconomic, harvest, and management scenarios. We demonstrate that management performance varies under future climate conditions, and that trophic interactions can both amplify and attenuate climate impacts. Our results reinforce the importance of conducting multiple climate and management projections that can provide the contrast and breadth of scientific support needed to operationalize policy tradeoff evaluations under future climate change.

**June 5, 11:30/S12-Oral-12921**

## **Modeling the manager: Getting catch right to improve integrated climate-fisheries projections**

Amanda **Faig**<sup>1</sup> and Alan Haynie<sup>2</sup>

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In the United States Bering Sea and Aleutian Islands, an ecosystem cap constrains the total allowable catch (TAC) across all species in the fishery management plan to be less than 2 million metric tons. After the allowable biological catch (ABC) is proposed for each species by stock assessment scientists and approved by scientific advisory bodies, the North Pacific Fishery Management Council (Council) then decides how to allocate TAC among the managed species. Frequently, the sum of single-species ABCs exceeds the cap considerably, requiring the Council to reduce the TAC below the ABC for many species. Next, catch rarely is equal to this TAC due to a variety of policy and species-interaction reasons. Being able to predict TAC and catch from the ABC is essential to produce realistic predictions when conducting management strategy evaluations. Naively assuming that catch would equal TAC and ABC would produce very misleading predictions. We examine and model the historical relationships among species and fleets under the ecosystem cap. We develop a model that enables us to explain and accurately predict both the TAC and catch of each species. These predictions can be incorporated into projection models, including those in the Alaska Climate Integrated Modeling (ACLIM) project. We provide an essential link for integrated model forecasts to make realistic representations of the management and fishing process and, as a result, realistic representations of what the stock will look like under future climate change.

**June 5, 11:50/S12-Oral-12644**

## **The future of crab in the Bering Sea**

Cody **Szuwalski**<sup>1,2</sup>, William Stockhausen<sup>3</sup>, Christine Stawitz<sup>3</sup>, Robert Foy<sup>4</sup> and Anne Hollowed<sup>3</sup>

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Crab stocks in the Bering Sea are some of the most valuable in the U.S., but their future is uncertain given projected environmental change. We present a size-structured population dynamics framework that combines down-scaled output of global climate models with laboratory studies and regional ocean modeling to produce spatial projections of the future distribution and productivity of crab under different scenarios of climate change. Bio-economic layers incorporating projected costs of fishing and ex-vessel prices allow for the quantitative evaluation of management strategies from both a biological and economic perspective. We compare the projected biological and economic performance of management strategies that incorporate the effects of environmental change on growth and recruitment to management strategies that do not consider these effects. The presented framework is generalized and can be implemented for any species for which size-structured dynamics (*i.e.* populations in which aging is difficult) anywhere in the world (code is available on github).

**June 5, 12:10/S12-Oral-12924**

## **Salmon responses to climate change: From life cycle models to a multi-model approach**

Lisa **Crozier**

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Chinook salmon are a key cultural and economic resource in the North Pacific. Salmon migrate between freshwater and marine environments, and hence are especially complex in their climate sensitivity and exposure. Furthermore, despite extensive research, the interplay of bottom up and top down controls on salmon are still not fully understood. We therefore lack realistic projections for salmon responses to climate change. In this talk, I review the different take-home messages that resulted from different modeling approaches for salmon in the northern California Current Ecosystem, including qualitative vulnerability assessments, population-specific life cycle models, intermediate complexity models and end-to-end models. I the present a proposal for moving forward through a multi-model approach.

**June 5, 12:30/S12-Oral-13177**

## **A predictive fisheries catch metric for CMIP6-OMIP Earth System models**

Cheryl S. **Harrison**<sup>1</sup>, Samantha Stevenson<sup>2</sup>, Nicole Lovenduski<sup>1</sup> and Jessica Luo<sup>3</sup>

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Observed fisheries catch in large marine ecosystems (LMEs) have been empirically linked to observed rates of secondary production and benthic detrital flux, resulting in the development of fisheries catch metrics that have high predictive skill for an Earth system model with validated representation of secondary production, with the best performing metric relying on productivity rates of mid-to-large zooplankton (Stock *et al.*, 2017). However, most Earth system models do not simulate multiple zooplankton types, nor is zooplankton production a standard model output variable in the upcoming 6th Climate Model Intercomparison Project (CMIP6) Ocean Model Intercomparison Project (OMIP). Here we modify the Stock *et al.* 2017 fish catch metrics to use variables available in CMIP6-OMIP simulations, resulting in comparable predictive skill. This predictive catch metric is then applied to the Community Earth System Model (CESM), including the CESM Large Ensemble, to explore the effects on climate variability on fisheries catch across the global LMEs.

**June 5, 12:50/S12-Oral-13038**

## **The future status of trophic regimes of the global ocean**

Momme **Butenschön**

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Primary Production and sea-surface temperature are the main environmental variables influencing the trophic state of an ecosystem in providing the metabolic energy available to marine organisms. While the rise of global average sea surface temperature with climate change is an established and undisputed fact in the scientific community, recent works have provided increased levels of evidence and certainty in the decline of global average primary production. These changes will doubtlessly impact the trophic regimes of the global ocean and their extent, and ultimately determine the amount of food that the global ocean is capable to deliver sustainably.

This work investigates the evolution of these regimes under various future conditions of climate change by applying an unsupervised artificial neural network algorithm to define the trophic regimes of the global ocean on an ensemble of future projections from the CMIP5 archive of the two key variables considering each ensemble member's capability to represent their short-term variability with respect to estimates from satellite imagery. In a training phase of the algorithm, the mean levels and seasonal cycles of temperature and primary production at present day conditions are used to define the trophic regimes, the evolution of which is projected in a second step classifying the future data.

This ensemble approach allows for an unprecedented, well constrained map quantifying the future extends of the trophic regimes of the global ocean under varying mitigation strategies.

**June 5, 14:20/S12-Oral-12910**

### **EcoTroph, a quasi-physical ecosystem model to analyze the global impact of climate change on marine food-webs**

Didier **Gascuel**<sup>1</sup>, Hubert Du Pontavice<sup>1,2</sup> and William W.L. Cheung<sup>2</sup>

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EcoTroph is a trophic-levels-based ecosystem model, where the structure of the ecosystem is represented using only trophic spectra (i.e. the distribution of biomass or production across trophic levels). The ecosystem functioning is reduced to a flow of biomass entering the ecosystem with the primary production or detritus recycling and surging up the food-web (from low to upper trophic levels) due to predation and ontogenic processes. Here, we show how EcoTroph can be used to analyze the various effects of climate change on food-web functioning. EcoTroph tells us that three key aspects will be affected: the biomass inputs at trophic level 1, the trophic efficiency of each trophic level, and the flow kinetics through the food-web. Thus, based on recent pre-existing global analyses, we identified the direction and the range of change that can be expected for the value of each parameter due to ocean warming. In particular, warmer oceans are likely to result in faster and more efficient trophic transfers, while primary production would decrease in low latitudes. Then, using EcoTroph, we simulated the effects of climate change on three virtual ecosystems mimicking polar, temperate and tropical food-web functioning. We show that total biomass and biomass of predators would be affected, while expected catches based on current level of fishing would decrease everywhere. Results suggest that the decrease in primary production would be the main driver of change in tropical water, while in temperate and polar ecosystems changes in trophic flow kinetics would play the major role.

**June 5, 14:40/S12-Oral-12897**

### **Projecting global fishing effort dynamics in the 21<sup>st</sup> century under climate change**

Vicky W.Y. **Lam**, Andres Cisneros and William W.L. Cheung

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Previous studies assessing climate change impacts on marine fisheries focus on the impacts from changing ocean conditions on fish distribution, fish catch and the related human well-beings. However, these studies often use simple assumptions of fishing effort scenario without accounting for the effects of changing productivity of living marine resources, fisheries management measures, and the economics of fishing on fishers' behavior and fishing effort. Here, we develop and apply a holistic approach for projecting future impacts of climate change on global fisheries by linking a fishing effort dynamic model with the Dynamic Bioclimate Envelope Model (DBEM). In each time-step (year or fishing season), spatial and temporal changes in fishing effort are predicted based on changes in catch and profitability of the exploited species while DBEM projects changes in species distribution and abundance under climate change and fishing effort. In the effort dynamic model, fishers are assumed to seek to maximize their profit given the constraints imposed by management measures e.g., catch quotas, with the consideration of economic factors such as price, operating cost of fishing, cost for purchasing a new vessel and the depreciation cost of the fishing vessels. We show that the effort dynamic model can broadly reproduce historical changes in fishing level. Projections of future catches with the consideration of effort dynamics can be substantially different from previous studies with simple fishing effort assumption. Thus, this study highlights the importance of projecting and applying plausible fishing scenarios in understanding climate change impacts on fisheries.

**June 5, 15:00/S12-Oral-12583**

### **Modeling the global marine capture fish market under climate change**

Oai Li **Chen** and William W.L. Cheung

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This paper presents a market model that captures the complex dynamics of the global marine capture industry. Climate change and other human activities are altering the distribution and production of marine fish stocks and fisheries. Given that fish is the most traded food commodity worldwide, climate-induced changes in regional fisheries production is expected to affect seafood supply elsewhere through the global market. However, the extent of such tele-connection and their implications for ocean sustainability are not clear. Here, we develop a new economic model that links the behavioral dynamics of the key actors in the fish market: fishers/producers, consumers and traders. It is a partial equilibrium model that simulates annual changes in global fish supply, demand and trade, at species group and national levels. It is applied to understand how market forces may interact with climate-induced changes in fish production on global fish products. We assess the sensitivity of the simulated fish supplies, prices and human consumption patterns to exogenous non-market and market factors. The results show that the model is a rigorous analytical tool that can be applied to project future seafood utilization and economics under scenarios of climate change and socio-economic development. The findings further highlight that national fisheries industries and markets cannot be considered in isolation from the interactions at global level. The model can be further expanded to incorporate differential behavior of consumer group (*i.e.*, income level) and marketing agents (*i.e.*, retailer) to explore a wide range of questions related to seafood sustainability under climate change.

**June 5, 15:20/S12-Oral-12870**

### **Exploring future seafood sustainability under scenarios of climate change and socio-economic development**

William W.L. **Cheung**<sup>1</sup>, Oai Li Chen<sup>1</sup>, Andrés Cisneros-Montemayor<sup>1</sup>, Vicky W.Y. Lam<sup>1</sup>, Muhammed Oyinlola<sup>1</sup>, Gabriel Reygondeau<sup>1</sup>, Jorge Sarmiento<sup>2</sup>, Charles Stock<sup>3</sup>, Louise Teh<sup>1</sup>, Lydia Teh<sup>1</sup> and Colette Wabnitz<sup>1</sup>

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Global seafood production from fisheries and aquaculture contributes substantially to the food security, health, economic benefits and livelihood opportunities of our society. Sustainable seafood production is constrained by biophysical, economic and social factors through ocean primary productivity, trophic dynamics, the economics of fishing, market access and dynamics, as well as local and global ocean governance. Simultaneously, human activities and their consequences such as fishing, carbon emissions, pollution and habitat destruction are driving ecological and social-economic changes. However, global studies seldom integrate these multiple human and natural drivers and their interactions into a holistic framework to understand the implications of climate change for future seafood sustainability. In this study, we developed a marine integrated assessment model (IAM) that incorporated changes in ocean conditions, fish stocks, fisheries, mariculture and seafood markets at the global scale. Applying the IAM to four globally-traded seafood products (salmon, tuna, shrimp and sardine) as case studies, we projected substantial negative impacts of climate change on the conservation status (indicated by decrease in mean species abundance), economic benefits (indicated by decrease in fishing profits), and provision of food and livelihoods (indicated by decrease in catches and jobs generated) from these fisheries, at regional and global scales. Results also illustrate that fishing and other social-economic scenarios play a significant role in the projected sustainability of these seafood commodities. The findings highlight the importance of integrating climate change and society's socio-economic pathways in understanding the future global seafood sustainability and potential opportunities for climate adaptation.

**June 5, 15:40/S12-Oral-13207**

### **Development of robust management strategies for Northeast groundfish fisheries in a changing climate**

Lisa A. Kerr<sup>1</sup>, Gavin **Fay**<sup>2</sup>, Sarah Gaichas<sup>3</sup>, Steven X. Cadrin<sup>2</sup> and Andrew Pershing<sup>1</sup>

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Climate-mediated change in the Northeast U.S. Shelf Large Marine Ecosystem (NESLME) is unprecedented, and impacts on marine fisheries resources are increasing. Some groundfish stocks in the NESLME have declined to record-low biomass in recent years, with others increasing. Understanding the likely performance of fisheries management procedures that consider climate-driven changes is necessary to evaluate whether these approaches will result in more adaptive and successful fisheries. Our multispecies approach uses Management Strategy Evaluation (MSE) to: 1) evaluate how principal Northeast groundfish stocks will respond to regional climate change, 2) investigate plausible approaches for tailoring management procedures to prevailing environmental states, and 3) quantify expected ecological and economic performance of management alternatives in a changing climate. Here we outline a set of single species operating models parameterized to emulate the effects of temperature scenarios on NESLME groundfish population dynamics. Simulated data from these models will be used by candidate assessment models, reference points, and harvest control rules that vary in their approach for including temperature change and non-stationarity. Performance metrics will provide comprehensive views of economic and ecological risks and returns of management alternatives. Vetting candidate procedures with simpler operating models that do not include technical interactions among species helps to: 1) identify procedures unlikely to be successful, and 2) provide a baseline for best possible expected outcomes given no constraints from quota availability for other species. These results will be needed to disentangle interactions between climate change effects and fishery dynamics, to understand the value of 'climate ready' management options.

**June 5, 16:00/S12-Oral-13008**

### **Evaluating adaptation scenarios for fishing communities facing climate-driven species changes**

Bradley **Franklin**<sup>1</sup>, Brian Kennedy<sup>1</sup>, Jenny Sun, Katherine E. Mills<sup>1</sup>, Andrew Allyn<sup>1</sup> and Eric Thunberg<sup>2</sup>

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Climate projections indicate that ocean temperatures will continue increasing, potentially shifting the distribution of marine fish species and affecting the economics of the fishing industry and fishing communities. In this study, an integrated ecological-economic framework is used to evaluate the economic impacts of climate-driven species changes and assesses the value of specific adaptation strategies available to fishermen. A quantitative species distribution model coupled with qualitative expert vulnerability assessment ratings is used to project relative changes in the presence of over 50 commercially important fish species out to 2050 based on ocean temperatures projected by the CMIP5 ensemble of climate models (RCP 8.5 scenario). The results are used to estimate changes in species catchability, which are used as inputs to a port-specific economic optimization model. The optimization model assumes profit-maximizing behavior by the commercial fishing fleet at each port and adjusts the effort level of fishing activities— defined by the combination of gear used, vessel size, and species targeted— to changes in catchability. Future adaptation scenarios are elucidated through interviews and focus groups with fishermen and municipal leaders in diverse New England ports. The economic model is then used to assess how adaptation scenarios can buffer climate-related impacts and to evaluate the relative value of different adaptation options, such as switching gear types, species targeted, and fishing location. We also consider specific policy changes that may be required to facilitate adaptation and measure the potential benefits of such changes.



**June 5, 16:40/S12-Oral-13188**

### **Climate vulnerability and resilience in the most valuable North American fishery**

Arnault **Le Bris**<sup>1</sup>, Katherine E. Mills<sup>2</sup>, Richard A. Wahle<sup>3</sup>, Yong Chen<sup>3</sup>, Michael Alexander<sup>4</sup>, Andrew Allyn<sup>2</sup>, Justin Schuetz<sup>2</sup>, James Scott<sup>5</sup> and Andrew Pershing<sup>2</sup>

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Managing natural resources in an era of increasing climate impacts requires accounting for the synergistic effects of climate, ecosystem changes, and harvesting on resource productivity. Coincident with recent exceptional warming of the northwest Atlantic Ocean and removal of large predatory fish, the American lobster has become the most valuable fishery resource in North America. Using a model that links ocean temperature, predator density, and fishing to population productivity, we show that harvester-driven conservation efforts to protect large lobsters prepared the Gulf of Maine lobster fishery to capitalize on favorable ecosystem conditions, resulting in the record-breaking landings recently observed in the region. In contrast, in the warmer southern New England region, the absence of similar conservation efforts precipitated warming-induced recruitment failure that led to the collapse of the fishery. Population projections under expected warming suggest that the American lobster fishery is vulnerable to future temperature increases, but continued efforts to preserve the stock's reproductive potential can dampen the negative impacts of warming. This study demonstrates that, even though global climate change is severely impacting marine ecosystems, widely adopted, proactive conservation measures can increase the resilience of commercial fisheries to climate change.

**June 5, 17:00/S12-Oral-12591**

### **Forecasting herring productivity in the Gulf of St. Lawrence fishery: When the environment matters for management**

Pablo **Brosset**<sup>1</sup>, Thomas Doniol-Valcroze<sup>2</sup> and Stéphane Plourde<sup>1</sup>

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The mounting evidence of the important role of environmental drivers on pelagic fish productivity underscores the pressing need to develop assessment and management approaches that account for the effects of future environmental conditions. For herring in the Gulf of St Lawrence (GSL), cold environmental conditions promote spring spawners productivity while warm conditions promote fall spawners. The objective of our work was to use a Management Strategy Evaluation on *GSL herring stocks* to assess the performance of different management strategies accounting for the future environmental scenarios that could be experienced by herring stocks. When testing the 'no fishing' management strategy, predicted herring spawning stock biomass (SSB) is similar to historical levels when F was low, regardless of the climate projection. However, the different levels of future warming in the GSL induced low spring herring productivity and then a high probability of severe decrease in SSB and catches within 15 years for most of the management strategies. Conversely, fall herring productivity and then SSB seemed to be favoured with the future warming. Reference points and optimal management strategies were thus influenced by the incorporation of the environment in the model, highlighting the risk of continuing to overlook environmental variability. Although still in progress, this work is highly relevant for future improvements of stock assessment models and should contribute to the on-going discussion about the understanding of the interactions between human and natural marine systems under climate change.

**June 5, 17:20/S12-Oral-12774**

### **Implications of environmentally-driven movement and productivity of Atlantic bluefin tuna**

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Climate, oceanographic, and biological factors are important determinants of the spatial-temporal distribution of Atlantic bluefin tuna, and substantial shifts in distribution have been documented in response to a changing ocean environment. Atlantic bluefin tuna are currently managed as separate eastern and western stocks, but stock identification methods indicate populations exhibit extensive and dynamic stock mixing. Analysis of fish caught in the U.S. fishery suggest a majority of catch in the 1990s came from the Gulf of Mexico with the majority of recent catch originating in the Mediterranean. Using a simulation model, we explored how scenarios of population-specific migration and shifts in productivity affect the long-term magnitude, distribution, and mixed-stock nature of the resource and fishery catch under current fishing conditions. The analytical framework was a stochastic, age-structured, seasonally, and spatially explicit stock-overlap model with movement of eastern- and western-origin tuna informed by telemetry. Simulation of the model indicated considerable stock mixing in the western and central Atlantic, which resulted in differences between the stock and population view of western bluefin tuna. Relative biomass of the western population and its spatial and temporal distribution in the Atlantic was sensitive to the alternative assumptions of separate or overlapping stocks. We developed biological reference points that incorporate the influence of mixing, as well as different productivity regimes with implicit climate hypotheses. Alternative management strategies were tested against the goal of sustainability of eastern and western populations and consider the impact exploitation of each stock has on the other with different productivity scenarios.

**June 5, 17:40/S12-Oral-13067**

### **An intermediate complexity food web model to explore fisheries management scenarios under climate change**

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Models of intermediate complexity for ecosystem assessments (MICE) focus on the components of the ecosystem needed to address the main effects of the management questions under consideration while allowing rigorous statistical data fitting and uncertainty quantification, in contrast to more complex ecosystem models. Under climate change, "business as usual" scenarios are unlikely and changes in fisheries dynamics are expected as result of socio-economic interactions, like changes in demand and costs of fisheries exploitation impacting profitability and inducing effort reallocation over the different fleets. Consequently, the response of marine ecosystems to climate change may be altered by these changes in the human interactions. In order to better understand the tradeoffs between resource exploitation and socio-economic benefits, we developed an intermediate complexity fisheries food web, using the Bay of Biscay Ecosystem to design a simulation study. The model considers several functional groups interacting through generic length-based predation functions. The full life cycle for each functional group is considered and fisheries can target different functional groups with an explicit time-varying selectivity and effort. The simulation study includes four CMIP5 based climate change environmental scenarios and dynamic effort allocation based on economical drivers and the instantaneous abundance of the main commercial groups. The model is used to study the effectiveness of alternative management procedures while accounting for uncertainty in the economic and environmental drivers, testing the efficiency of different climate mitigation and adaptation choices.

**June 5, 18:00/S12-Oral-12935**

### **The future of Australia's fisheries – A multi-model analysis**

Heidi R. Pethybridge<sup>1</sup>, Elizabeth **Fulton**<sup>1</sup>, Alistair Hobday<sup>1</sup>, Julia Blanchard<sup>2</sup>, Catherine Bulman<sup>1</sup>, Ian Butler<sup>3</sup>, William W.L. Cheung<sup>4</sup>, Rebecca Gorton<sup>1</sup>, Trevor Hutton<sup>1</sup>, Hector Lozano-Montes<sup>1</sup>, Richard Matear<sup>1</sup>, Greta Pecl<sup>2</sup>, Eva Plagányi<sup>1</sup>, Cecilia Villanueva<sup>2</sup> and Xuebin Zhang<sup>1</sup>

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The level of existing uncertainty about the structure, function and responses of marine ecosystems - and their constituent species – means that an ensemble model approach is the most robust means of considering potential ecosystem responses to climate change. In this study, projections of 14 models of Australian waters (including Ecopath, Atlantis, Species distribution and Size-spectrum models) forced by high-resolution Ocean Forecasting Australian Models were assessed. We found that each Australian region will likely face its own challenges in terms of ecosystem shifts and fisheries management over the next 40 years. Demersal systems appear to be more strongly effected by climate change than pelagic systems, with species (particularly invertebrate species) in shallow waters likely to be amongst those to respond first and with the greatest magnitude of responses. Intercomparison of model simulations of species at the regional level were challenging, but with the assistance of a qualitative credibility evaluation, the ensemble approach was useful for identifying management strategies and priorities. Study results show that fisheries and their management will need to foster pro-active and flexible adaptation options to make the most of coming opportunities and to minimize risks or negative outcomes.

## **S13: Multiple stressors at multiple scales: Ecosystem based management in the face of changing ocean conditions**

**June 5, 11:00/S13-Invited-13036**

### **How can we use imperfect knowledge to inform management of ecosystems facing multiple drivers?**

Sarah Cooley

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Overlapping, accelerating human-caused ocean drivers including warming and acidification, pollution, resource extraction, and loss of sea ice, oxygen, biological diversity, and vertical exchange are placing today's marine ecosystems in conditions entirely different from those of just a century or two ago. Perturbation experiments have identified many marine organisms' responses to small groupings of environmental drivers, and generalized mechanistic explanations for observed responses are emerging. Meanwhile, computational power has improved so much that we can now simulate whole marine ecosystems, including human predators. But resource users are not rational actors, so marine resource policies and management do not always follow straightforwardly from ecosystem-scale information. Obstacles remain that hinder full incorporation of multiple-driver, whole-ecosystem information into marine resource management. Although these obstacles often are well outside the traditional scope of marine science, innovators are overcoming some of them. For instance, new products bridge communication gaps and supply more high-level insights than ever to non-scientists. Environmental scorecards, integrated assessment tools, risk and tradeoff analyses, and scenario analyses now help illustrate the potential impacts of changing marine resources on ecosystem services and socioeconomic metrics. Continued transdisciplinary work is needed to bring ecosystem-level insights into policy and decision making in ways that facilitate decision making under uncertainty, reduce risk, engage communities, and build on shared values. Attention to overcoming the non-scientific obstacles that hinder the policy process will in fact aid the incorporation of cutting-edge ecosystem-scale marine science into resource management.

**June 5, 11:30/S13-Oral-12840**

### **Linear or non-linear? Understanding the effect of climate change on Atlantic cod recruitment**

Camilla Sguotti, Saskia Otto, Romain Frelat and Christian Möllmann

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Climate change is transforming marine systems by affecting physical oceanographic processes and variables such as currents and temperature. Year-class strength, i.e. recruitment of commercially important fish stocks such as Atlantic cod (*Gadus morhua*), is critically affected by these often rapid and abrupt abiotic changes. Recruitment of fish stocks is assumed to be primarily determined by spawner, i.e. adult biomass, followed by a multitude of density-independent processes during immature life-stages. These early life-stages are sensitive to physical ocean processes and hence statistical models for predicting recruitment increasingly include environmental variables as predictors in addition to spawner biomass. However, traditional recruitment models, being conceptually linear, are often poorly predicting future year-class. Here, we test whether novel non-linear and state-dependent modelling approaches help increasing predictive performance. We compared traditional environmentally-sensitive Ricker stock-recruitment models with two non-linear approaches; (i) the stochastic CUSP model derived from catastrophe theory and (ii) the Empirical Dynamic Modelling, a recently developed approach based on attractor state space reconstruction. Using stock assessment data of 19 Atlantic cod stocks we modelled recruitment dependent on spawner biomass and environmental variables characterizing North Atlantic climate and ocean physical conditions, i.e. Sea Surface Temperature, the Gulf Stream Index and Indices for the North Atlantic and Atlantic Multidecadal Oscillations. We show that Atlantic cod recruitment largely follows non-linear dynamics with state-dependent importance of adult stock size and environmental conditions.

**June 5, 11:50/S13-Oral-12660**

**Multiple pressures at multiple time-scales: How climate change, fishing, nutrient inputs, and socio-political events shaped the sizes of plaice from 1902 to now**

Georg H. **Engelhard**<sup>1,2</sup>, John Pinnegar<sup>1,2</sup> and Ewan Hunter<sup>1,2</sup>

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Climate change, fishing, changing nutrient inputs from rivers, and political events have been major drivers of the North Sea ecosystem over the past 115 years – as reflected in long-term changes in the size distribution of a major fish stock. We present what might be the world’s longest time-series on fish size distribution – North Sea plaice *Pleuronectes platessa* – collated from archives at Cefas (UK, 1902–present) and ICES (1966–present). In the early 1900s when intensive trawling commenced, large plaice were abundant but already declined before WWI. During the 1920s–1930s, fishing was intense; lack of large plaice raised concerns of overfishing. Fishing halted during WWII, allowing plaice to recover with many large, older fish by war’s end. After fishing recommenced, large fish became scarcer in the 1950s. Unexpectedly in the 1960s–1970s, despite introduction of mechanised beam-trawling, large plaice were again prevalent, likely linked to a stark increase in riverine nutrient inputs due to agricultural fertilisers, and possibly indirect trawling effects, resulting in high polychaete prey availability favouring faster growth. Smaller sizes again became more common after 1980, likely reflecting substantial warming, sustained high fishing, and reduced nutrient inputs following stricter policies on fertilisers – relationships supported statistically by GAMMs. Stomach contents analysis confirms a dietary shift, from bivalves to polychaete worms, and reflecting a fundamental reorganisation in North Sea benthos: originally dominated by slow-growing bivalves, now by fast-reproducing, trawling-resistant organisms. This exceptional time-series disentangles the cumulative effects of fishing, eutrophication, prey availability and political events, on top of climate change.

**June 5, 12:10/S13-Oral-12981**

**The effects of climate on Baltic salmon: An application of Structural Equation Models**

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Many studies examined the effects of climate variations and environmental conditions on the traits (e.g., size, weight, age structure, maturation, and survival rate) and the migration behavior of Atlantic salmon (*Salmo salar*), for the salmon populations in both Atlantic Ocean and Baltic Sea. However, little studies explored the influences of such climate variations and environmental conditions on the population dynamic of salmon. Focusing on the salmon population from River Torne at the north of Baltic Sea, this study applies Structural Equation Models (SEM) to explore the cause-effect relations among large-scale climate index, local climate variables, freshwater environment, ocean physical characteristics, fisheries, and the salmon population at different life stages. For salmon at the spawning stages, North Atlantic Oscillation (NAO) winter and the smolt numbers that are one to four years beforehand affect the spawner population significantly. Spawner population is also weakly influenced by sea surface temperature and sea surface salinity. Offshore and coastal fisheries have high correlations to the spawner population, but the cause-effect links are insignificant in the SEM results. Smolt numbers mainly depend on the parr density in the river. However, Atlantic Multidecadal Oscillation (AMO) and air temperature significantly influence the parr density. The results are further about to apply into a multispecies bio-economic model which includes the food web interactions among salmon, herring and grey seal, as well as herring and salmon fisheries in the Baltic Sea. The results could serve as input for ecosystem-based management.

**June 5, 12:30/S13-Oral-12907**

### **Multiple stressors cause alternative stable states in the Baltic ecosystem**

Christian **Möllmann**<sup>1</sup>, Thorsten Blenckner<sup>2</sup>, Michele Casini<sup>3</sup>, Romain Frelat<sup>1</sup>, Alessandro Orio<sup>3</sup>, Camilla Sguotti<sup>1</sup> and Saskia Otto<sup>1</sup>

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Climate change is interacting with local anthropogenic stressors such as fisheries and eutrophication to significantly alter coastal marine ecosystems. The dramatic and often surprising changes are so-called regime shifts that result in reorganization of ecosystem structure and function. While abrupt shifts are increasingly reported, it is however generally unclear how multiple pressures interact in causing ecosystem changes. Furthermore, it remains difficult to evaluate if post-shift states can be characterized as stable or just transient. Here we analyzed abrupt changes in the structure of two connected sub-basins of the Central Baltic Sea ecosystem. These sub-basins are strongly affected by different combinations of external stressors. We first use Local Linear Embedding, a non-linear dimension reduction technique, to derive integrative state indicators from matrices of >20 individual, multi-trophic ecosystem indicators. Using time-series changepoint analysis techniques we tested for the occurrence of abrupt changes in integrative state indicators. Subsequently, we evaluated how external pressures interact in causing abrupt change using Stochastic CUSP Modelling, a non-linear statistical technique derived from catastrophe theory. The CUSP approach allowed us further to evaluate the stability of ecosystems states and potential hysteresis in response to manageable drivers. Our study demonstrates spatial differences in the stability of ecosystem states in the Central Baltic Sea to a large degree induced by increasing oxygen deficiency in the bottom water, a combined result of climate change and eutrophication. Our results provide information on the nature of ecosystem changes, crucially important for the development of ecosystem-based management in the Central Baltic Sea and beyond.

**June 5, 12:50/S13-Oral-12749**

### **Long-term variabilities in ecosystems structure of China Seas and the possible mechanisms of atmosphere-ocean-ecosystem process**

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As marginal seas of the western Pacific Ocean, China Seas are largely influenced by the Kuroshio Current and its branches and have experienced decadal shifts in marine environment. Anthropogenic activities such as intensive fishing have also generated considerable impacts on China Seas at both species- and community-levels, including over-exploitation of commercial species and changes in species composition and trophic structure of the ecosystems. However, variabilities and processes in the ecosystems structure and functioning have not been well understood in China Seas with overfishing working in tandem with climate change. In this study, we integrated biological and physical time series data including catches of 148 taxa, 14 local-scale and 17 basin-scale climate indices to explore the variation patterns in the ecosystems structure, and to elucidate the effects of climate change on the Yellow Sea (YS) and the East China Sea (ECS) ecosystems during 1950-2014. Results showed that decadal variations occurred in both YS and the ECS with step changes around the mid-1960s, mid-1970s, late-1980s and late-1990s. These changes responded well to the contemporaneous climatic regime shifts in the Pacific. In addition, a try of subtracting relative fishing efforts indices from catches was made to eliminate the effects of fishing on the fish communities, and results showed evident climate-induced changing patterns, indicating that different fish communities with diverse sensitivities responded differently to climate change. Increasing water temperature exhibited larger effects on cold-water species than on temperate-water species, and least effects on warm-water species. The dynamics of demersal species and small pelagic species were largely associated with climate change while large predatory species and invertebrates were hardly affected by climate change. Our results provided strong evidences for climate-induced variations in over-exploited marine ecosystems and the coupled "Atmosphere-Ocean-Ecosystem" influencing mechanism, which had important implication for ecosystem-based fisheries management in China Seas.

**June 5, 14:20/S13-Oral-12620**

### **How do fishing and climate change interact to impact biomass available to future fisheries?**

Phoebe **Woodworth-Jefcoats**<sup>1,2</sup>, Julia Blanchard<sup>3</sup> and Jeffrey C. Drazen<sup>2</sup>

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Projecting how Hawaii's longline fishery will change in the future requires that we understand the greatest stressors on its supporting ecosystem, namely climate change and fishing itself. Furthermore, we need to understand how these stressors will influence the ecosystem in concert with one another. We use a size-structured food web model with individual species embedded to address this question. The model includes fishing mortality, as well as dynamic ocean temperature and phyto- and zooplankton biomass. By incorporating these primary drivers of ecosystem change, we are able to examine their impact on future fish biomass available to Hawaii's longline fishery. We assess the role that fishing mortality plays in restructuring the size and species composition of the ecosystem. We also study the impact of changing ocean temperatures across species' full vertical habitat, as well as the influence of changing plankton communities. By examining these stressors individually and in combination with each other, and by forcing the model with output from a suite of CMIP5 models, we can project a range of future scenarios. This range of scenarios is used to help quantify the uncertainty surrounding the impact future ocean change will have on the provisioning of ecosystem services. These scenarios have potential to guide future management strategies by allowing managers to analyze a suite of possible future outcomes.

**June 5, 14:40/S13-Oral-12542**

### **Under pressure: Fisheries and climate change in a highly vulnerable marine ecosystem**

Javier **Porobic**<sup>1</sup>, Elizabeth Fulton<sup>2,3</sup>, Stewart Frusher<sup>3</sup>, Carolina Parada<sup>4</sup> and Billy Ernst<sup>5</sup>

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A major disruption in an ecosystem can be caused by humans activities (*e.g.* fishing), the environment (*e.g.* extremes events) or synergistically by both. This disruption can have severe consequences for the ecosystem and for the services that they provide. The sensitivity and speed of recovery of an ecosystem to these disturbances define its vulnerability. A vulnerable marine ecosystem, such as seamounts, is one that after being disturbed show a slow recovery. One such ecosystem is the Juan Fernández Ridge Ecosystem (JFRE), an aseismic chain of seamounts and islands located off the coast of central Chile. Two commercial fishing fleets have historically operated in this ecosystem: i) a long term traditional coastal artisanal tightly-knit fishing community associated with the islands, and ii) a mainland based industrial demersal finfish fishery operating on the seamounts, currently closed due to overexploitation. Due to the vulnerability of this area and the potential for expansion of the current artisanal fishing fleet and mainland based fishing activities towards higher levels of finfish exploitation, it is extremely relevant to assess the sustainability of this ecosystem under both increased exploitation and predicted climate change scenarios. To address this question, we developed an end-to-end model that includes the main ecological and physical processes of the JFRE as well as a representation of the impact of fishing activity. Using this model, we explore the effect of different scenarios of fishing pressure and climate change on the JFRE.

**June 5, 15:00/S13-Oral-12569**

### **OSIRIS: A new analytical framework for evaluating compounding climate stressors in the ocean**

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In the last three decades, climate change has grown from an important area of scientific inquiry to the single greatest threat to the habitability of the planet and human well-being. In the ocean, while habitat destruction and overfishing continue to top the list of critical, near-term threats, there is growing worry that climate-driven ocean changes will combine with these direct drivers to push marine systems into new, dysfunctional states. There is a pressing need for an effective analytical framework to quantify the role of multiple stressors and to evaluate the consequences of interacting climate and non-climate stressors on marine systems.

We have developed a new, network node model (OSIRIS – Ocean Systems Interactions, Risks, Instabilities and Synergies) as a versatile framework within which to explore the system consequences of multiple external environmental forcings. The model is a hierarchical structure of interconnected nodes that allows for external forcings to be described additively, synergistically or antagonistically. The first instantiation of the model is a coarse-grained, non-spatial, ‘whole system’ model of the California Current ecosystem. We focus on the impacts of ‘global’ forcings (temperature, pH and dissolved oxygen) and on the highly uncertain nature and strength of interactions among these effects. Results indicate that the degree to which interactions are synergistic is crucial in determining sensitivity to forcing, particularly for higher trophic levels. Stronger synergistic interactions also sensitize the system to noise in the forcing; in particular, combinations of stronger forcing, noise and synergies result in cascading food web collapse across the system.

**June 5, 15:20/S13-Oral-13069**

### **Incorporating physical forcing in a marine ecosystem model for developing optimal fisheries management strategies**

Caihong **Fu**<sup>1</sup>, Yi Xu<sup>1</sup>, Jackie King<sup>1</sup>, Norm Olsen<sup>1</sup>, Yongjun Tian<sup>2</sup>, Huizhu Liu<sup>3</sup>, Philippe Verley<sup>4</sup> and Yunne-Jai Shin<sup>4,5</sup>

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With the emerging worldwide movement towards ecosystem-based management, ecosystem models have become increasingly important tools for mimicking real-world systems, identifying potential risks, conducting simulation experiments to anticipate consequences of climate change and future conditions that are impractical to conduct in the real world, and evaluating alternative management strategies against such climate change and future conditions. In this study, we use a series of atmospheric and oceanographic indices, including basin- (Pacific Decadal Oscillation, North Pacific Gyre Oscillation, and Multivariate ENSO Index) and regional-scale (sea surface temperature, sea surface height, chlorophyll-a concentration, and upwelling index) to force biological processes in an end-to-end ecosystem model (OSMOSE, Object-oriented Simulator of Marine Ecosystems) developed for the Pacific North Coast Integrated Management Area (PNCIMA) ecosystem off western Canada. The OSMOSE-PNCIMA model simulates the dynamics of 28 taxa covering different trophic levels. Simulation experiments indicate that various pathways of physical forcing on larval mortality and body growth of fish species impact differently on the productivity of fish species at different trophic levels. Focusing on two commercially important species, Pacific Herring (*Clupea pallasii*) at low trophic level and Pacific Cod (*Gadus macrocephalus*) at high trophic level, we recommend how fisheries management should respond to potential environmental changes by developing climate-oriented and trophic-specific management strategies.



**June 5, 15:40/S13-Oral-12748**

## **Projections of ocean acidification impacts on marine species and fisheries, for the California Current Integrated Ecosystem Assessment**

Isaac **Kaplan**<sup>1</sup>, Kristin Marshall<sup>1</sup>, Emma E. Hodgson<sup>2</sup>, Albert Hermann<sup>3</sup>, Shalin Busch<sup>1, 4</sup>, Paul McElhany<sup>1</sup>, Christopher Harvey<sup>1</sup> and Elizabeth Fulton<sup>5</sup>

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The California Current off the US West Coast is fueled by upwelling that drives high productivity but also leads to lower pH. Ongoing increases in atmospheric CO<sub>2</sub> will further drive declines in ocean pH (ocean acidification), with negative impacts on shelled organisms and other species. As part of an Integrated Ecosystem Assessment (IEA), we developed an Atlantis ecosystem model to project impacts of acidification on lower trophic levels, harvested and protected species, and fishery catches. Fifty-year projections of Atlantis were forced by a Regional Ocean Modeling System (ROMS), coupled to a GFDL Earth System Model including IPCC CO<sub>2</sub> scenario RCP 8.5. We conducted an extensive literature review to develop scenarios for the biological response of calcifying organisms to pH. The most dramatic direct effects of ocean acidification in the Atlantis projections were expected on epibenthic invertebrates such as crabs, shrimps, some sea urchins, and bivalves. Strong indirect effects were expected on some demersal fish such as rockfish (*Sebastes* spp.), sharks, and Dungeness crab (*Metacarcinus magister*) because they consume species known to be sensitive to changing pH. In the management context, scale mattered: model results suggest the strongest effects of acidification on nearshore state-managed invertebrate fisheries, and on northern fishing communities. With a suite of other risk assessment tools and forecasting efforts, the results are being presented to the Pacific Fishery Management Council to support a Fishery Ecosystem Plan climate initiative. Necessary next steps include extending the modeling to the Mexican and Canadian portions of the California Current.

**June 5, 16:00/S13-Oral-12574**

## **Using ecosystem models to evaluate how climate change influences ecological indicators' response to fishing effects in the southern Benguela system**

Kelly **Ortega-Cisneros**<sup>1</sup>, Lynne Shannon<sup>2</sup>, Kevorn Cochrane<sup>1</sup>, Elizabeth Fulton<sup>3</sup> and Yunne-Jai Shin<sup>4</sup>

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Ecological indicators used to monitor fishing effects in the context of climate change and variability need to be informative to enable effective ecosystem-based fisheries management. We evaluated the specificity of ecosystem indicators' response to different fishing and environmental pressure levels using Ecosim and Atlantis ecosystem models for the southern Benguela system. Three fishing strategies were modelled to represent a variety of fishing strategies: one focused on low trophic levels (*i.e.* forage species), another on higher trophic levels (*i.e.* predatory fish) and a third that put fishing pressure across the full range of potentially exploitable species. Two types of environmental change were simulated for each fishing mortality scenario – random environmental variability and directional climate change. The specificity of selected ecological indicators (mean trophic level of the community, proportion of predatory fish, biomass/landings, mean intrinsic vulnerability and marine trophic index) was evaluated for different combinations of fishing strategy, fishing mortality and both types of environmental change. Ecosim and Atlantis have different underlying assumptions and model structures. It is therefore of interest that the specificity of the ecological indicators considered under changing climate generally corresponded between the two models. Certain indicators were less specific in detecting ecosystem effects of fishing in some of the three fishing strategies modelled under climate change. This helped refine the most appropriate indicator set for our system, reflecting the focus of a particular fishing strategy, and improved confidence in the suitability of these indicators for monitoring fishing effects in the Southern Benguela.

June 5, 16:40/S13-Oral-12928

## Scaling climate impacts from individual-level processes to populations and food webs using multispecies size spectrum models

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Information on the impacts of climate variables such as temperature and ocean acidification (OA) on individual-level parameters (*e.g.*, body growth and survival rates) has grown rapidly, but modeling approaches are needed to scale results up to populations and food webs to understand their potential influence on ecosystems services. Multispecies size spectrum models (MSSMs) are based on the observation that marine predators generally consume smaller sized prey. System dynamics emerge from individual-level processes (growth, predation, survival, reproduction) that are determined by a small set of parameters which, in turn, can be forced by ocean conditions. The models offer a strong conceptual framework for linking climate impacts on individual-level parameters to food web-level consequences. We parametrized a MSSM for the eastern Bering Sea, one of the most productive shelf systems in the world, and coupled ocean temperatures to consumption and natural mortality rates. Further, we examined three sets of OA hypotheses using the model: OA would (1) alter phytoplankton productivity; (2) reduce the productivity of zooplankton and benthic invertebrates with calcifying body parts; and (3) alter the vulnerability of crabs to fish predators. We show the individual and interactive effects of temperature and OA on emergent properties of the food web (*e.g.*, community size structure, species diversity) and species harvests under a range of future climate emissions scenarios. Predicting climate impacts on food webs remains a daunting challenge, but size-based models offer promising strategic tools that may aid decision making under future climate conditions.

June 5, 17:00/S13-12837

## Detecting catastrophic transitions – The case of North Atlantic herring

Leonie **Färber**<sup>1</sup>, Camilla Sguotti<sup>2</sup>, Joël Durant<sup>1</sup>, Øystein Langangen<sup>1</sup>, Saskia Otto<sup>2</sup> and Christian Möllmann<sup>2</sup>

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Large scale structural changes, commonly termed regime shifts, have been increasingly documented for marine ecosystems especially in the North Atlantic. Changing climate is a major driver of regime shifts, interacting with direct anthropogenic pressures such as overfishing. However, if observed changes can be classified as true catastrophic transitions, characterized by discontinuity and showing hysteresis when it comes to recovery is still largely unclear and widely debated. Here, we test if 15 stocks of Atlantic herring (*Clupea harengus*), a species of high commercial value, follow true catastrophic dynamics. First, we developed a new approach for detecting abrupt and significant regime changes in adult spawner biomass by combining various statistical change point analysis techniques. Only the stocks showing significant abrupt changes were then tested for discontinuous behavior (thus catastrophic changes) using the *stochastic CUSP model* that builds on the catastrophe theory. We model potential catastrophic changes depending on climate indices (North Atlantic and Atlantic Multidecadal Oscillations), sea surface temperature, fishing mortality, and predation by the predator cod (*Gadus morhua*). We show that herring in the Western Baltic, the North and Norwegian Seas as well as in the Gulf of Maine displayed abrupt and true catastrophic changes. According to our models, catastrophic changes were mostly due to overfishing but modulated by physical ocean changes and predation pressure by cod. Our results indicate that Atlantic herring are very resilient to environmental changes when sustainably harvested. Eventually we provide a novel approach to detect true catastrophic changes based on time-series from large marine ecosystems.

**June 5, 17:20/S13-Oral-13052**

## **Impacts of ocean warming, acidification and fishing on marine food-web dynamics and human user groups in the Barents Sea region**

Stefan **Koenigstein**<sup>1,3</sup>, Hauke Reuter<sup>2</sup>, Hans-Otto Pörtner<sup>3</sup> and Stefan Gößling-Reisemann<sup>1</sup>

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The Barents Sea possesses a wealth of marine fish resources, but ongoing warming and future acidification may cause substantial changes in the marine ecosystem, impacting fisheries productivity and other ecosystem services. We investigated potential impacts of ocean warming and acidification in the Barents Sea region and societal adaptation options, by involving stakeholders from different sectors, developing integrative models as tools for ecosystem-based management, and incorporating experimental and observational data. A novel fish stock recruitment model integrates future stressor effects on early life stages of Atlantic cod, and a process-based multi-species model explores potential shifts among fish populations. Average recruitment of Barents Sea cod will likely be reduced by the combined impacts of warming and acidification in the second half of the 21st century – an additional safety margin in catch quota for the spawning stock would thus be advisable to prevent recruitment failures. Shifts among the major fish stocks under warming can be ameliorated through catch reductions, but capelin, an important forage fish, is projected to undergo marked food-web mediated decreases. Indirect impacts are projected for seals and seabirds, which will affect marine tourism and cultural ecosystem services. Management of marine resources and areas should thus improve consideration of user groups with lower adaptive capacities in the Far North, such as small-scale fishers and tourism operators. This work demonstrates how stakeholder involvement and integrative models can be used to assess ecological and societal impacts for combined drivers, establishing tools for ecosystem-based governance of climate change impacts in the oceans.

**June 5, 17:40/S13-Oral-12712**

## **Ocean acidification explored using a suite of end-to-end ecosystem models covering ecosystems from the tropics to the arctic**

Erik **Olsen**<sup>1</sup>, Isaac Kaplan<sup>2</sup>, Cameron Ainsworth<sup>3</sup>, Gavin Fay<sup>4</sup>, Sarah Gaichas<sup>5</sup>, Robert Gamble<sup>5</sup>, Raphael Girardin<sup>6</sup>, Cecilie Hansen<sup>1</sup>, Thomas F. Ihde<sup>7</sup>, Hem Nalini Morzaria-Luna<sup>8,9</sup>, Kelli F. Johnson<sup>10</sup>, Marie Savina-Rolland<sup>6</sup>, Howard Townsend<sup>11</sup>, Mariska Weijerman<sup>12</sup>, Elizabeth Fulton<sup>13,14</sup> and Jason S. Link<sup>15</sup>

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Ecosystem-based management (EBM) of the ocean considers all impacts of human activities as well as drivers caused by climate change and ocean acidification. End-to-end ecosystem modelling frameworks have proved to be central in assessing the global responses to climate change. In the present analysis, we leverage the global advances in ecosystem modelling to explore common opportunities and challenges facing eight marine ecosystems, ranging from the tropics to the arctic, under increased ocean acidification (OA) compared to a common baseline of no increase. We also compare the OA scenarios with scenarios of increased marine protected areas (MPAs) and

changes in fishing pressure. The analysis was carried out using the Atlantis ([atlantis.cmar.csiro.au](http://atlantis.cmar.csiro.au)) end-to-end modelling framework. Our results suggest stronger impacts from OA compared to increasing MPAs or altering fishing pressure, both in terms of guild-level (*i.e.*, aggregations of similar species or groups) biomass and in terms of indicators of ecological and fishery structure. Effects of OA were typically negative (reducing biomass across all species or groups), while marine protected areas led to tradeoffs (both 'winners' and 'losers') at the level of particular species (or functional groups). Effects were weaker for species guilds than at single species indicating a compensatory effect within a species guild to external perturbation. The present analysis highlight how OA may become a key driver on marine ecosystems in a future under increased CO<sub>2</sub> levels, likely overshadowing even the impacts of radical changes to management of human ocean uses.

**June 5, 18:00/S13-Oral-12813**

### **Adaptation design tool for ecosystem-based management: Coral reef application**

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Scientists and managers have communicated an urgent need for improved methods and tools for effective adaptation of ecosystem-based management activities in light of climate change. In response to calls for practical support in this area, an inter-agency team has developed an Adaptation Design Tool that uses a structured approach to break down an otherwise overwhelming and complex thought process into tractable steps. The tool guides users through a series of design considerations to (1) adjust their currently-planned management actions to be more climate-smart and (2) brainstorm and craft additional adaptation actions to address remaining vulnerabilities. Developed in collaboration with partners in Hawai'i and Puerto Rico using coral reefs as a pilot ecosystem, the tool and associated reference materials consist of worksheets and instructions as well as an on-line, interactive training module. Based on stakeholder feedback and collaborative case studies, we present lessons learned on how to maximize tool efficiency, gain the greatest value from the thought process, and deal with issues of scale and uncertainty. While initially tested for coral reefs, the tool is also fully transferable to and beginning to be used for other systems and sectors such as wetlands and seagrass restoration, and toxic contaminant management. These diverse applications demonstrate how the Adaptation Design Tool advances the theory and practice of assessment and decision-making science, informs higher level strategic planning, and serves as a platform for systematic, transparent and inclusive thought processes to tackle the practical implications of climate change for ecosystem-based management.

## **S14: Vulnerability and adaptation of marine socio-ecological systems to climate change**

**June 6, 11:00/S14-Invited-12783**

### **Living in a world of change – Juggling cumulative impacts and path dependency**

Elizabeth **Fulton**

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In coping with global change and the expanding blue economy, integration, flexibility and adaptation are likely to be key. However, as societies navigate their way through global change they must live with “cascades of consequences” (*sensu* Gould) which constrain possible future paths. With the best of intentions resource management has taken a particular path – proposing an integrated strategic view, but defaulting to operational objectives that may not be consistent with that vision. Advice has also often journeyed from one “silver bullet” management direction to another, again losing the importance of integration in the struggle to deal with the day-to-day reality of implementing management actions. We draw on simulation models, human psychology and history to explore the implications for future management of the oceans (and associated cumulative impact assessment tools) of path dependency in marine socioecological system dynamics.

**June 6, 11:40/S14-Oral-13004**

### **Humans at risk. Global spatial patterns of ocean ecosystems degradation and governance scales**

Emanuele **Bigagli**<sup>1</sup>, Liana Talaue-McManus<sup>2</sup>, Robin Mahon<sup>3</sup>, Benjamin S. Halpern<sup>4</sup>, Lucia Fanning<sup>5</sup> and Albert Fischer<sup>6</sup>

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Anthropogenic-induced ocean ecosystem degradation puts human communities at increased risk. Our study aims to examine two questions: (1) Where and how much are human communities at risk from ocean degradation? and (2) What is the most appropriate mix of governance scales to address ocean degradation and related risk? We estimate risk as the interaction of hazard, exposure and vulnerability for 239 Exclusive Economic Zones (EEZs) of the world. We use expert judgement to determine the appropriate mix of global, regional and national governance solutions needed to address and where possible, mitigate, a diversity of ocean hazards. Based on this, we calculate the proportion of hazard and related risks needing global, regional and national governance solutions. Results show that risk to humans from ocean degradation has a wide geographical variability. Of the three components of risk, hazard is the main driver for Europe, Australia and New Zealand while Africa and South America risk scores are driven by higher vulnerability. Both hazard and vulnerability play important roles in influencing risk in Central America and the Caribbean while exposure accounts for the higher risk scores of Asian countries. In relative terms, all EEZs of the world are mostly at risk from hazards needing transboundary (*i.e.* global + regional) governance solutions, with Antarctica and the Small Islands Developing States (SIDS) at highest relative risk. This study highlights the global spatial patterns of risk components and identifies the need for increased transboundary cooperation to tackle the main drivers of risk to humans from ocean degradation.

**June 6, 12:00/S14-Oral-13118**

## **Translating ocean acidification into practical applications to support aquaculture and food sustainability**

Silvana N. R. **Birchenough**<sup>1</sup>, Cristian A. Vargas<sup>2</sup>, Stefan Gelcich<sup>3</sup> and Bernardo R. Broitman<sup>4</sup>

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Aquaculture is a key activity in support of food provision for the increasing global population, which is an important development goal. The aquaculture production has grown steadily over the past decades, surpassing the rate of global population growth and is now the fastest growing food production system worldwide. The aquaculture activities have generated a diverse group of species including fish (66.6 million tons/yr), algae (23.8 tons/yr) and molluscs (15.1 tons/yr). This overall trend may account for 60% of seafood by 2030. Over half of marine aquaculture production (~53%) now comes from aquaculture in the ocean's coasts and estuaries. As a large fraction of the world's population inhabits the coastal zones, these areas are highly exposed to anthropogenic impacts, such as pollution and sediment runoff. However, one of the major changes taking place in the oceans are of global nature and arise from the increase in CO<sub>2</sub> in the atmosphere over the past century. These increased atmospheric CO<sub>2</sub> concentrations are absorbed by the ocean, resulting in changes of the carbonate chemistry of the seawater (refer to as *Ocean Acidification*). Commercial shellfish species, chiefly bivalves and crustaceans are exposed to these changes showing some sensitivities to these changes. This work has synthesised all the available experimental OA evidence for shellfish commercial species. The information was then used to develop adaptation options for the aquaculture sector under OA effects. The potential adaptation options were then evaluated with a socio-ecological questionnaire. The respondents suggested that whilst OA could a threat there will be other more pressing co-stressors. Similarly, more issues associated with licensing, meeting market and demand as well as seed production could have more detrimental effects over the shorter time-scales for the industry sector.

**June 6, 12:20/S14-Oral-12728**

## **Developing adaptation and management strategies for socio-ecological systems in an acidified ocean**

Laura J. **Falkenberg**<sup>1</sup>, Sam Dupont<sup>2</sup>, Brooks Kaiser<sup>3</sup>, Wenting Chen<sup>1</sup>, Philip Wallhead<sup>1</sup>, Camilla W. Fagerli<sup>1</sup>, Magnus D. Norling<sup>1</sup>, Kumiko Azetsu-Scott<sup>4</sup>, Ann-Dorte Burmeister<sup>5</sup>, Lars Ravn-Jonsen<sup>3</sup> and Richard G. J. Bellerby<sup>1,6</sup>

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Human societies derive economic benefit from marine systems, yet natural resource extraction can alter the providing ecosystems. Understanding the reciprocal links between natural systems and human societies is important to sustainably maintain, or enhance, economic benefits obtained now and in the future. A key environmental change with the potential to alter both ecosystems and the reliant human societies is ocean acidification. Despite the importance of this issue, its emergent nature means that there are not yet established techniques to explore questions of concern. Here I will discuss case studies included in the upcoming Arctic Monitoring and Assessment Programme's 2018 report on Arctic Ocean Acidification (AMAP AOA 2018). In particular, I will focus on case studies using different approaches to consider the effects of ocean acidification on: 1) the urchin harvesting industry in northern Norway, and, 2) the shrimp fishery in Greenland. In each of these case studies the regional environmental changes are linked with key biological elements and the resulting socio-economic implications. This information is then placed within the context of locally-relevant strategies for adaptation and management of the fisheries in an acidified ocean. Our experiences working on these disparate case studies indicates that, while these approaches represent a step toward better understanding, there is still much to be done to ensure the development of appropriate adaptation and management strategies for socio-ecological systems in an acidified ocean.

**June 6, 14:00/S14-Oral-13034**

### **A pragmatic approach to developing climate adaptation plans for fisheries and aquaculture**

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Climate change has been observed to have a significant impact on the distribution and productivity of aquatic species. This will affect the level of food production, the livelihoods of communities that depend on fisheries and aquaculture, and the future sustainability of the fisheries and aquaculture sectors. Coping with the impacts from climate change requires an adaptive and efficient management. This study aims to develop a pragmatic and comprehensive framework to conduct impact and vulnerability assessments and to develop climate adaptation plans for fisheries and aquaculture. The method is built on IPCC (2012; 2014) and FAO (Brugère and Young 2015) approaches for vulnerability assessments and adaptive management. These are being tailor-made at regional level, for each sector and each component of a production system, so that managers, operators and other stakeholders can reduce the negative effects of climate change on their activity and find effective ways to utilize all potential opportunities that may arise. The work conducted is being done in collaboration with stakeholders in the EU H2020 ClimeFish project, but the approach is designed to enable other users, regions and areas not covered by the project to develop their own climate adaptation plans. Practical examples of the framework applied in both fisheries and aquaculture case studies will be presented. The paper will also focus on the challenges met when applying the framework and suggest potential ways to overcome them.

**June 6, 14:20/S14-Oral-13040**

### **An index to assess the vulnerability of ocean planning and the Blue Economy to global climate change**

Catarina **Frazão-Santos**<sup>1</sup>, Tundi Agardy<sup>2</sup>, Francisco Andrade<sup>1</sup>, Manuel Barange<sup>3</sup>, Larry B. Crowder<sup>4</sup>, Charles N. Ehler<sup>5, 6</sup>, Michael K. Orbach<sup>7</sup> and Rui Rosa<sup>1</sup>

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Planning of marine areas is being developed worldwide to foster sustainable ocean management and governance. Marine spatial planning (MSP), as it is most often termed, is a process that aims to organize the use of the ocean space, as well as the interactions among human uses and between uses and the marine environment. On top of the many challenges that developing and implementing MSP already face, global climate change will present an additional and evolving challenge. However, very few guidelines exist on how to assess the vulnerability of MSP to a changing climate. Building on a set of specific variables we develop a robust and systematic approach for measuring the resilience and exposure (the main two vulnerability dimensions) of MSP to global climate change. This approach entails the assessment of the vulnerability of seven-main uses of the ocean space (*i.e.* marine conservation, fisheries, aquaculture, shipping, tourism, renewable energy, and seabed mining) using it as a proxy for MSP vulnerability. The index simultaneously investigates the vulnerability of the Blue Economy to a changing climate. Although the index can be implemented at higher (global) and lower (sub-national) scales, here we present results of its application to European Union coastal countries. As with other composite indices, this approach provides standardized, quantitative and transparent measures that can be used to better inform policy-makers, environmental managers and the overall society, further supporting sustainable management of the ocean space.

**June 6, 14:40/S14-Oral-12884**

**Building capacity to address climate impacts at marine protected areas**

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Marine Protected Area (MPA) and other coastal and marine managers in the United States and around the world are evaluating how climate change will impact the resources they are entrusted with and what strategies can be implemented to build more resilient marine and associated human communities. MPAs provide a wide range of services -- including food production, recreation, storm protection and cultural identity – that may be affected by climate impacts. Although MPA ecosystems are diverse, the processes and strategies for building resilient ecosystems and communities are similar. This talk will highlight a recent rapid vulnerability assessment tool for MPA managers developed by the Commission for Environmental Cooperation and EcoAdapt and applied at several MPAs in North America. It will discuss brief case studies and lessons learned in working through vulnerability assessments and adaptation planning at the site and community level in the United States and other countries. Major challenges have included: how to identify and prioritize actions with limited information, engaging key community groups and stakeholders, and building new partnerships to leverage resources and work at the landscape scale.

**June 6, 15:00/S14-Oral-12979**

**Climate change impacts on marine species, communities and habitats: Implications for managing conservation features, marine protected areas and the wider implementation of marine biodiversity legislation**

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The effects that changes in temperature, salinity, ocean chemistry and extreme events are having on marine biodiversity present challenges to the conservation of marine habitats and species. For example, many features (species, communities and habitats) that marine protected areas are designed to protect are sensitive to changes in climate. As the distribution and state of marine habitats and species changes in the future, so the quality, composition and presence of features will be altered at protected sites and in wider marine protected area networks. Here we present findings from recent studies undertaken by the Marine Climate Change Impacts Partnership (MCCIP) on the implications of climate change for marine biodiversity legislation. Case studies on the vulnerability of specific marine conservation features to climate change are presented, and potential management options explored. Broader issues for the implementation of national, EU and international legislation that include marine biodiversity are discussed, including the mechanisms that exist within these obligations to 'accommodate' impacts of climate change. Finally, wider challenges, and opportunities, for the conservation of marine species, habitats, and communities in a changing climate are discussed.



**June 6, 15:20/S14-Oral-12612**

**Operationalizing ecological adaptive capacity: Assessing vulnerability, resilience, and action for coral reefs in French Polynesia under global environmental change**

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Coral reefs, already under pressure from local threats (e.g. overfishing, coastal pollution), are one of the socio-ecological systems most vulnerable to global environmental change. Scientific indicator-based assessments have been developed to understand changes in socio-ecological systems and guide decision-makers and managers and to monitor and evaluate progress towards environmental management. The diversity of the human and ecological states of coral reefs requires a diverse set of tools and management strategies to best handle the increasing intensity of threats posed by climate change and ocean acidification in specific environmental contexts. We propose the concept of “ecological adaptive capacity (EAC)” that defines the maximum potential ecological state of a reef in the absence of local environmental stress. Identifying the EAC of a reef helps to prioritize the potential for improved (i) resilience, (ii) recovery, (iii) ability to avoid losses of ecosystem services (which requires human adaptation). To go from theoretical thinking towards operational assessments of EAC and integration of vulnerability and resilience thinking, we attempt to formalize the relationships between the components identified by these two fields. We use participative approaches and construct indicators to incorporate local ecological knowledge to help quantify EAC in the context of French Polynesia. The goal of these approaches is to engage the local scientific community, policy-makers, managers, and the local communities that depend on coral reefs to assess resilience and vulnerability and help public policy plan for adaptation.

**June 6, 16:20/S14-Oral-12679**

**Pacific Canadian fish stock climate change vulnerability assessment**

Karen **Hunter**<sup>1</sup>, Helen Drost<sup>2</sup>, Joy Wade<sup>3</sup>, Miranda Smith<sup>4</sup> and Mike Foreman<sup>5</sup>

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Commercial fisheries off Canada’s Pacific coast rely on a highly diverse species assemblage that is expected to be impacted as anthropogenic climate change alters the region’s marine systems. We used a rapid climate change vulnerability assessment based on projected change in ocean temperature to systematically assess vulnerability of fish and fisheries along the British Columbia coast. We determined spatially-explicit thermal safety margins for the adult life stage of 16 commercially important species across their fishery footprints, fishery depth distribution, and fishing season using Regional Ocean Model Systems projections of ocean temperature at 10 depth slices. Each grid cell was assigned a thermal safety margin score and then joined with results from a fish-focused, literature-based evaluation of climate change sensitivity using a logic model. Species scores were merged with average seasonal catch and visualized in a GIS as hotspots on the fishing grounds. Results demonstrate that localized portions of historic fishing grounds for many important target species will be more vulnerable to climate change with southern and shallower sections of the BC coast exceeding species thermal limits with greater frequency. A third set of attributes developed separately to assess climate change adaptation barriers in fisheries governance were applied as the adaptive capacity component of vulnerability. We found that Pacific Canadian fisheries with area-based harvest restrictions, lower enforcement, and higher complexity in catch allocation had lower relative adaptive state. Results identify key knowledge gaps and possibly will assist with research prioritization and adaptation planning.

**June 6, 16:40/S14-Oral-13223**

## **Comparing Climate Vulnerability Assessment of Fish and Shellfish Resources across Large Marine Ecosystems**

Myron Peck<sup>1</sup>, Elliott **Hazen**<sup>2</sup>, Katherine E. Mills<sup>3</sup>, Eddie Allison<sup>4</sup>, Ignacio Catalan<sup>5</sup>, William W. L. Cheung<sup>6</sup>, Lisa Colburn<sup>7</sup>, Julia Ekstrom<sup>8</sup>, Karen Hunter<sup>9</sup>, Elena Ojea<sup>10</sup>, Mark R. Payne<sup>11</sup>, Gretta Pecl<sup>12</sup>, John Pinnegar<sup>13</sup>, Nancy Shackell<sup>14</sup> and Paul Spencer<sup>15</sup>

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Within large marine ecosystems around the world, Climate Vulnerability Assessments (CVAs) have been or are being conducted on fisheries and aquaculture species and the human communities that depend on these resources. These CVAs can help identify research needs, raise awareness of marine fisheries and aquaculture industries to climate-driven risks and opportunities and can inform policymakers charged with developing climate adaptation plans for sustainable resource use and future resilience of coastal communities. This presentation compares and contrasts CVAs stemming from work in Australia, Canada, Europe, the USA, and global analyses. Although each of the 25 CVAs discussed here used the FAO framework (e.g. vulnerability is a function of exposure, sensitivity, and adaptive capacity), their goals and, hence, their methodologies differed markedly, from rapid literature-based assessments to local community engagement. CVAs based on natural science have relied on indicators of vulnerability at spatial scales often independent from CVAs based on social science. The next generation CVAs need to be highly interdisciplinary and utilize spatial approaches that capture the unequivocal connections between marine systems and the prosperity of human communities. At local and regional scales, participatory processes are critical to contextualize risks to stakeholders and communities, foster engagement, and support science communication and transparency. We highlight upcoming plans for conducting socio-ecological CVAs on fish and shellfish resources in North America, Europe, Australia and elsewhere.

**June 6, 17:00/S14-Oral-12900**

## **Fuzzy logic approach for integrated assessment of vulnerability of marine fisheries**

Robert **Blasiak**<sup>1,2</sup>, William W. L. Cheung<sup>3</sup>, Andrés Cisneros-Montemayor<sup>3</sup>, Vicky W. Y. Lam<sup>3</sup> and Colette Wabnitz<sup>3</sup>

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Understanding the future of marine fisheries in the context of climate change requires consideration of a suite of diverse social-ecological factors. Marine pollution, changes in fishing behavior, shifting nutritional dependencies, and changes in the distribution and abundance of fish stocks due to climate change are just some of the relevant variables. While patterns of exposure may be uniformly high across certain regions for multiple stressors, other regions are expected to show greater variance. It is therefore important to consider vulnerability to individual stressors as well as an aggregation of multiple stressors. Yet a substantial barrier to such integrated assessments is the high degree of variance in quality and completeness of corresponding datasets. Fuzzy logic has been effectively used by Cheung et al. (2005) and others to address such data challenges. Here we will introduce preliminary results (e.g. regarding heuristic rules and thresholds for incorporating relevant socio-ecological variables into a new fuzzy logic system) of an integrated assessment of national vulnerability of marine fisheries to multiple stressors.

**June 6, 17:20/S14-Oral-12663**

### **Ecological, socioeconomic and institutional resilience to shifting fish stocks**

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Climate change is already impacting fisheries around the globe causing stocks to move from one fishing area to another. Adaptation in this context goes beyond managing for productivity changes, as regulations and spatial arrangements in the oceans provide an extra layer to the set of impacts expected from climate change in transboundary fisheries. On top of the fisheries ecological resilience, socioeconomic and institutional resilience allow for adaptation to the set of impacts expected from distributional shifts. The resilience or capacity of the fisheries to be maintained without transformation to a different state (*e.g.* collapse) has not been measured in all three dimensions for shifting stocks. Here we take a resilience approach to compare the capacity of European Union fishing countries to adapt, for eleven stocks of two species that have been observed to significantly shift their distribution in European waters: hake (*Merluccius merluccius*) and cod (*Gadus morhua*). We identify a set of resilience factors from the literature and propose measurable indicators that are combined into a novel index that displays resilience on the ecologic, socioeconomic and institutional dimensions of the fisheries. Results show that there is a latitudinal gradient where southern countries have higher institutional resilience for the studied species than northern countries. However, ecological resilience in southern countries is lower than in northern countries, illustrating the poleward direction of the shifts. The approach contributes with the operationalization of resilience in fisheries and can be replicated and transferred to other shifting species around the globe.

**June 6, 17:40/S14-Oral-12614**

### **Assessing vulnerability and adaptive capacity in the fisheries sector of Dominica: Long-term climate change and catastrophic hurricanes**

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The Commonwealth of Dominica is a Small Island Developing State (SID) in the eastern Caribbean, that has been subject to a wide variety of natural hazards over the past century (hurricanes, volcanic eruptions, land-slips etc.) and most recently Hurricane Maria on 18-19th September 2017. Fishing in Dominica is largely artisanal in nature. While there are small-scale reef and demersal fisheries, pelagic fisheries have tended to dominate and fishers make extensive use of Fish Aggregating Devices (FADs). Dominica's GDP per capita stands at 7,362 US\$ (2016), which is approximately 2,000 US\$ less than the average for Caribbean islands. As such fishing communities in Dominica are through to be especially vulnerable to long-term climate change and occasional catastrophic hurricanes. Vulnerability assessments provide a coherent framework for evaluating impacts over a broad range of species, but also socio-ecological systems. These methods assess the 'exposure' to a stressor (climate change and/or decadal variability) and the 'sensitivity' to that stressor. These two components are then combined to estimate overall vulnerability. In this study we make use of fisheries catch data from landing ports and parishes around Dominica, to assess relative vulnerability and adaptive capacity. We make use of information on species' temperature preferences and life-history traits as well as data on social vulnerability from a national household census, poverty assessment and fisheries survey in 2011. In the aftermath of Hurricane Maria - fisheries vulnerability has become a very immediate issue in Dominica, with >27% of all fishing vessels destroyed within a 24 hour period.

**June 6, 18:00/S14-Oral-12745**

### **Vulnerability of key Peruvian fishery species to Climate Change**

Jorge **Ramos**<sup>1</sup>, Jorge Tam<sup>2</sup>, Gretta Pecl<sup>1</sup> and Dimitri Gutierrez<sup>2</sup>

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The Peruvian portion of the Humboldt Current System is highly productive and sustains one of the most important fisheries of the world. However, the oceanographic conditions in the region are highly variable and appear to be associated with changes in catches of several commercially important species. Further changes in abundance, distribution and phenology of marine species in the region are expected due to climate change, with likely impacts on socio-economic activities associated with marine resources. Peru's livelihood and food security appear to have a moderate to high vulnerability to climate change due to its high dependence on fisheries. Moreover, Peruvian fish production is susceptible to decline in response to climate change. Therefore, a qualitative Climate Vulnerability Assessment was implemented to identify the relative vulnerability to climate change of 29 key Peruvian fishery species (*i.e.* pelagics, demersals, and invertebrates), through consultation with regional experts. The relative vulnerability of species was estimated based on the species sensitivity and exposure to 10 climate change parameters. Preliminary results indicate that 85% of the species had medium to high sensitivity. Demersal species were the most sensitive followed by invertebrates. The most sensitive species were corvina drum, Peruvian hake, catfish, mote sculpin, Peruvian rock seabass, and black ark. The least sensitive species were blue shark, mahi mahi, eastern Pacific bonito, and jumbo squid. Our findings may help resource managers, scientists and policy makers to anticipate and adapt to the potential impacts of climate change on commercially important species by prioritising research, minimising risks and maximising opportunities.

**June 8, 10:40/S14-Oral-12700**

### **Unravelling the effect of storms on commercial fish landings in UK waters**

Nigel C. **Sainsbury**<sup>1</sup>, Martin Genner<sup>2</sup>, John Pinnegar<sup>3</sup>, Clare K. O'Neill<sup>4</sup>, Geoffrey R. Saville<sup>5</sup>, Stephen Simpson<sup>6</sup> and Rachel Turner<sup>1</sup>

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Fish provide over three billion people with 20% of their animal protein and capture fisheries support the livelihoods of 12% of the global population. Weather and accompanying ocean conditions are a major factor in fishing decision making, but little research attention has focused on how weather conditions affect vessel landings. With growing evidence that global storminess is altering under climate change, there is now a need to better understand how fishery socio-ecological systems are disrupted by storms. We used the data rich case study of UK fisheries to explore how storms affect vessel landings for vessels over 10 metres in length across a variety of fisheries. Employing fine spatial and temporal resolution data over a ten year period from 2007—2016 for fish caught in the UK Exclusive Economic Zone, and employing generalized linear mixed-effect models, we explored how meteorological and oceanographic conditions affected landings and how this was moderated by vessel characteristics, gear types and harvested species. This work provides much-needed novel insights into how storm events and associated oceanographic conditions affect fishery productivity, which is critical for projecting socio-economic consequences of future climate change impacts.

**June 8, 11:00/S14-Oral-13044**

**Not all those who wander are lost – Fishers communities' responses to shifts in the distribution and abundance of fish resources**

Eva Papaioannou<sup>1,2</sup>, Rebecca Selden<sup>1</sup>, Kevin St. Martin<sup>1</sup> and Malin Pinsky<sup>1</sup>

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Fish resources in the NW Atlantic are sensitive to the impacts of climate change, with marked shifts in species' distribution already taking place. Fishing communities' response strategies to change are frequently neglected within policy, compromising the effectiveness of management schemes. We review (i) response strategies of NE USA fishing communities to changes in the abundance and distribution of major commercial species (summer flounder, red and silver hake) and (ii) how key characteristics of the fishery (e.g. species diversity) shape the choice of strategies. We make use of different methodological approaches (quantitative and qualitative) and data sources (ecological – trawl survey; fisheries; semi-structured interviews). Prominent response strategies included changes in fishing effort, port of landing and target species. Communities of large, mobile groundfish trawlers could respond to shifts in distribution and abundance more readily than their smaller, less mobile counterparts. The ability to respond to change was shaped by access to resource (quota, permits), proximity to fishing grounds, mobility of vessels, species diversity in catch, and diversity of gears. Communities with access to multiple permits and out-of-state permits had a comparative advantage in responding to change. Crucial response determinants also included fishers' observations and perceptions of change. Insight from such analyses are important in developing community adaptation plans. To that end, an interdisciplinary approach, such as the one presented in the talk, is key in assessing the impacts of climate change on communities, while accounting for invaluable fishers' ecological knowledge.

**June 8, 11:20/S14-Oral-12595**

**Social and climate change vulnerability in fishing communities of the United States: An examination of shifting baselines**

Lisa Colburn<sup>1</sup>, Patricia M. Clay<sup>1</sup>, Tarsila Seara<sup>2</sup>, Changhua Weng<sup>3</sup>, Angela Silva<sup>3</sup> and Jonathan Hare<sup>1</sup>

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Fishing communities have a heritage of species-specific harvesting unique to each region. While many fisheries range widely, fishery management regimes can limit fishing effort regionally. As species-range shifts occur in response to effects of climate change, fishing communities are also forced to adapt. Their ability to respond can be constrained by social and cultural norms, economics and management regimes. Representative Fishing Pathways (RFPs) represent one of several efforts to define mitigation scenarios for managers. RFPs are multi-model ensembles that incorporate projected physical change with biological and social responses. To be effective, approaches to mitigation must incorporate regional changes in fishing effort and species vulnerability to temperature and acidification. The National Oceanic and Atmospheric Administration is pursuing a goal of understanding the resilience and adaptability of coastal communities to impacts of hazards, including climate change. To meet this goal, indicators of social and climate change vulnerability and fishing reliance were developed for nearly 4,000 coastal communities. Climate vulnerability has been assessed for fish and shellfish species in the Northeastern US. An indicator for community reliance on climate vulnerable species was also developed. This linkage between social vulnerability and species vulnerability to physical change is a step towards development of mitigation approaches. Geographic shifts in community reliance on climate vulnerable species and species catch composition diversity have been investigated with time series and geospatial analyses. This provided an assessment of community dependence on climate vulnerable species in relation to other co-fished species and in relation to specific climate change vulnerability drivers.

**June 8, 11:40/S14-Oral-12697**

**Coastal index of vulnerability to climate change by economic zone (CIVEZ)**

Blair **Greenan**, Nancy Shackell, Andrew Cogswell, Philip Greyson, Kiyomi French and David Brickman

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Both ocean temperature and relative sea-level are projected to increase significantly in Atlantic Canada over the 21<sup>st</sup> century. The overall goal of this project is to provide information at a scale that is meaningful to fishery managers and coastal policy makers in the region. To that end, we assessed commercial fish vulnerability based on defined economic zones. We combined fish vulnerability scores with a parallel process that assesses adaptive capacity/vulnerability of coastal communities to sea-level-rise and storm surge, to create the Coastal Index of Vulnerability to Climate Change by Economic Zone (CIVEZ). Overfished species on the warmer, southern edge of their range are the most vulnerable to warming. Northern economic zones are expected to benefit from climate-driven warming because thermal habitat for lobster, a valuable fishery in Atlantic Canada, will expand. At the scale of economic zones, decision makers can use CIVEZ to develop informed coastal adaptation plans within their jurisdictions. Officials at higher levels of governance can use CIVEZ to prioritize resources towards vulnerable economic zones.

**June 8, 12:00/S14-Oral-13174**

**Adaptive fisheries management under changing environmental and economic conditions**

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The Alaska Climate Integrated Modeling (ACLIM) project is a multidisciplinary effort to examine how different climate scenarios are likely to impact the Bering Sea ecosystem – and to ensure that our management system is ready for these potential changes. ACLIM integrates climate scenarios with a suite of biological models which include different levels of ecosystem complexity and sources of uncertainty. This talk focuses on coupling the project's bio-physical models with models of fisher behavior and management. The complexity of the economic models varies to match the scale of the biological models with which they are coupled.

We identify groups of economic and management factors that are the core drivers of fisheries. For management, there are many possible future policy choices, such as changes in target and bycatch species allocations or expanded spatial protective measures that can reduce the vulnerability of different stakeholders. Building on shared socioeconomic pathways, we define the primary measures that have been shown to impact past fisher behavior and define a range of future economic changes and policy interactions under which we predict future integrated modeling outcomes. We demonstrate how different policy tools can have a large impact on how effectively we can adapt to environmental change and variation.

**Keywords:** fisheries management, climate change, integrated models, economics

**June 8, 13:40/S14-Oral-13095**

**Planning for future resilience of fishing communities to harmful algal blooms: What have we learned from the 2014-2016 northeast Pacific marine heatwave?**

Stephanie K. Moore<sup>1</sup>, Edward H. Allison<sup>2</sup>, Stacia J. Dreyer<sup>2,3</sup>, Julia Ekstrom<sup>4</sup>, Sunny L. Jardine<sup>2</sup>, Terrie Klinger<sup>2</sup>, Kathleen M. Moore<sup>2</sup> and Karma Norman<sup>1</sup>

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The 2014-2016 northeast Pacific marine heatwave resulted in a massive harmful algal bloom (HAB) of *Pseudo-nitzschia* along the entire U.S. West Coast that was unprecedented in its toxicity and geographic extent. The bloom produced a toxin called domoic acid that contaminated seafood resources necessitating fisheries harvest closures, beginning in May 2015, to prevent human illnesses. Extended and widespread closures of the lucrative commercial Dungeness crab and popular recreational razor clam fisheries were disastrous for the fishing communities that rely on them. Here we report on the economic, social and cultural impacts of the 2015 HAB across 17 fishing communities on the U.S. West Coast using primary interview and survey data. The survey instrument, deployed in the summer of 2017, collected sociodemographic and economic factors hypothesized to confer resilience to HABs as well as data that quantifies individual impacts. Preliminary analysis of the data indicates that community members in fishing-related occupations experienced greater impacts compared to those in other occupations. About 90% of respondents with a fishing-related occupation agreed or strongly agreed that the 2015 HAB caused stress in their lives and negatively affected their finances. We propose a framework, designed around three phases of disaster management and identifying roles of different levels of governance, for the development of disaster risk reduction and emergency response strategies to promote practical means of building resilience to HABs. As climate change advances and HABs worsen, these strategies will inform efforts to prepare for HABs, mitigate their impacts, and aid recovery of impacted communities.

**June 8, 14:00 REPLACEMENT (S14-P10, p. 297): Mark Payne  
Marine climate-change's tropical blindspot**

**June 8, 14:00/S14-Oral-12365 (CANCELLED)**

**Socio-ecological approaches to exploring climate change impacts: A case study of UK fisheries**

Katherine M. Maltby<sup>1</sup>, Jonathan Tinker<sup>2</sup>, Rachel Turner<sup>3</sup>, Martin Genner<sup>4</sup>, Simon Jennings<sup>5</sup> and Stephen Simpson<sup>1</sup>

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UK seas have warmed significantly over the last few decades due to climate change, and projections suggest further warming of 2–4°C by the end of the 21<sup>st</sup> century. This warming has impacted fish stocks and the wider marine environment and is increasingly affecting people who rely on these fish stocks for their livelihoods.

Using the south west UK as a case study, we used a socio-ecological approach to explore future climate change impacts on fisheries. Our modelling work indicates that there will be substantial changes to fish stocks in terms of their abundance and distributions, with projected declines of cold-adapted species such as megrim and cod, and increases in warm-adapted species such as red mullet and John dory. Yet, interviews with fishermen and industry representatives revealed that they perceive climate change as being of no/low risk to their fishing business or fisheries in general. Scepticism, age and perceived ability to cope with potential climate impacts appear to be key drivers. Our results suggest fish stocks within this region are vulnerable to future warming, yet currently fishermen perceive this to be of no/little risk to their fishing businesses in the future. Understanding how fishermen perceive and may respond to future climate change can help inform future adaptation strategies aimed at supporting fishing communities cope with change. The apparent disparity in stakeholder perspectives regarding how climate change may affect fisheries also highlights the importance of communicating climate change impacts to fishing communities that may be affected in the future.

**June 8, 14:20/S14-Oral-12796**

**A stakeholder-led process to design climate resilience strategies for wild-harvest commercial fisheries in Rhode Island, USA**

Sarah Schumann

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The state of Rhode Island is home to several fishing ports of varying sizes and a spectrum of vessels targeting numerous species at different scales. The Resilient Fisheries RI project brought together a diverse cross section of fishery participants to identify crosscutting themes related to climate adaptation and resilience. Through 48 one-on-one interviews, 10 evening seminars, one daylong scenarios planning workshop, and a broad industry-based review and feedback process, the project explored current and potential sources of climate vulnerability, and distilled several rules of thumb for building resilience and adaptive capacity in wild-harvest fisheries. Salient themes included alignment of decision-making jurisdictions to changing resource distributions, alignment of access to fishery resources with present-day resource distributions, alignment of the timing of seasonal management actions to coincide with seasonal resource distributions, diversity and flexibility in permitting, ecosystem-based fisheries management, addressing non-climate sources of environmental degradation, improving the knowledge base for fisheries management, increasing the pace and flexibility of fisheries management, innovative marketing as a route to market consistency and diversity, resilient social systems, and participatory governance. This project was itself highly adaptive, shifting its approach several times during the project period in response to fishing industry interests and priorities. Methodological lessons will be presented, with consideration of how this model might be applied in other places.

**June 8, 14:40/S14-Oral-12474**

**Effects of “The Blob” on profitability in the West Coast Pacific whiting fishery**

Lisa Pfeiffer

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The Pacific whiting fishery is one of the most economically important fisheries on the West Coast of the United States, with around \$50 million in annual landings. In general, the fishery is highly profitable. “The Blob”, or the large mass of warm water in the Northeastern Pacific Ocean, was first detected in 2013 and persisted through mid-2016. It was the “largest marine heatwave ever recorded” (Di Lorenzo and Matua 2016). The Blob has been associated with low primary productivity, an unprecedented toxic algal bloom that caused the largest-ever closure of the Dungeness crab fishery, unusual sea bird, whale, and sea lion mortality events, and warm-water species being detected in the northern California Current region. These anomalous ocean conditions had large and unexpected effect on the West Coast Pacific whiting fishery as well. This paper evaluates the socioeconomic impacts that The Blob had on the Pacific whiting fishery in 2104 and, primarily, 2015. Vessel-level profitability was between 41% and 76% lower than in 2015. We explore the drivers of this decline. Attainment of the TAC by each sector was extremely low in 2015; attainment is normally near 100% in the Pacific whiting fishery. CPUE was between 75% and 84% lower than normal in the second half of 2015, leading to higher search costs and leading to some vessels to stop fishing completely (the number of hauls by the at-sea mothership sector was 55% lower than normal in 2015). We quantify the effects of each factor on annual profitability and economic stability.



## **S15: Fisheries and aquaculture in the face of climate change: Current actions, identified solutions and opportunities in support of sustainable livelihoods and food security**

**June 6, 11:30/S15-Invited-12704**

### **The Blue Belt Initiative (BBI): Towards Sustainable Fisheries and Aquaculture for Building Resilience to Climate Change**

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Long-term sustainability of fisheries and aquaculture requires involvement of stakeholders at all stages of the policy from conception to implementation. Such practices will ensure that the productive capacity of the fish stocks is not depleted by over-harvest, and achieve the blue growth and blue economy objectives. Starting from a common need for climate action and for sustainability of fisheries and aquaculture, the Blue Belt Initiative (or BBI) was launched by Morocco in COP 22 in Marrakech as a solution to promote sustainable fisheries and aquaculture activities by offering ocean users solutions that transform their activities into sustainable practices. BBI priority solutions for adaptation are based on the ecosystem approach which can contribute to mitigating climate change as part of a roadmap «Climate SMART Solutions for Fisheries and Aquaculture». BBI proposes a collaborative platform to support the implementation of solutions for inclusion and contacting all of the components needed for successful solutions: Research, Innovation, Expertise, Government Institutions and Financial Institutions & Agencies. Focus areas includes integrated coastal monitoring systems, sustainable small-scale and large-scale commercial fisheries and aquaculture throughout the entire value chain. Key pilot and demonstration projects are on the way to show the feasibility of BBI such as the implementation of the concept of “user –observer” and the development of the fishing vessel of the future. BBI plays a crucial role in promoting south-south cooperation to achieve sustainable development. It supports other initiatives launched across Africa to bolster the fisheries sector as a driver for growth, while enhancing resilience to climate change through collective effort and transforming environmental constraints into economics opportunities.

**Key words:** Blue Belt, Ocean, Marine, Coastal, Fisheries, Small-Scale Fisheries, Aquaculture, Blue Growth, Morocco, West Africa, Ocean Observing Systems

**June 6, 12:00/S15-Oral-12598**

### **Social adaptation strategies of marine fishers to respond to climate change: The case of 'Tsunami' affected fishing hamlets in Tamil Nadu, India**

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Climate change has major impacts to the livelihoods of fishing communities. Small-scale coastal fisheries are highly vulnerable to climate change impacts and its concomitant outcomes. Such vulnerabilities call fisheries institutions (including traditional institutions) to think of the adaptation efforts and promote the community resilience of their society to face the present and future challenges of climate change. In this paper, through the case study, I discuss social and institutional adaptation strategies of small-scale coastal fisherfolk to cope and adapt to climate change. The research setting that was chosen to conduct this case study are the tsunami (2004) affected small-fishing hamlets in Tamil Nadu, India. The 2004 Indian Ocean Tsunami made extensive damages (long-term indirect effects) in the coastal areas of Tamil Nadu, India. Against this background, this paper addresses two research questions i) ‘Why’ and ‘How’ the lack (or inadequate) potential capital (social, economic, political and institutional) make the small-scale fisherfolk more vulnerable to climate change impacts? ii) How small-scale coastal fisherfolk socially adapt to the climate change impacts and what are their social and institutional adaptation strategies? Drawing from rich qualitative findings, I discuss how the roles and responsibilities of the fisheries institutions influence the ability of the community to make local adaptation (including coping) strategies to deliver both short and long-term flexible responses to climate change impacts. I argue that five sets of factors influence the community resilience of small-scale fisherfolk to adapt to climate change: information, institutions, social networks and economic and political capital.

**June 6, 12:20/S15-Oral-12613**

### **Evidence of ecosystem based adaption to climate change in coastal Bangladesh**

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Coastal waters of Bangladesh support extraordinary high levels of biological productivity including productive fisheries vital to the economy and food security of Bangladesh. At the same time, the Bangladesh coast is globally among the most vulnerable to climate change, where the coastal population are highly dependent on coastal ecosystem natural resources. The importance of fish habitats and biodiversity is enormous for the livelihoods of millions of people, trade, jobs and protein supply here. There is mounting evidence that demonstrate the impacts of climate change on fisheries.

Ecosystem Based Adaptation (EBA), a type of Ecosystem-based management, uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at different scales. Ecosystem based Adaptation (EbA) has great potential to increase people's resilience and ability to adapt, but it is not yet integrated in national and international policy processes and its use in fisheries sector is limited. In this study, we review a selection of community based adaptation practices that were developed as part of the CREL (Climate Resilient Ecosystem and Livelihoods) project along the coastal region of Bangladesh. We use an EbA framework to understand benefits and co-benefits, opportunities and challenges in management and adaptation of coastal ecosystems and fisheries to impacts of climate change.

**June 6, 14:00/S15-Oral-13086**

### **Effect of climate change on socio-economic conditions of fishermen – A tale from Kerala, India**

Dhanya Kandarattil

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This paper is to examine the contribution of fisheries to poverty reduction and food security, and portray the potential impacts of climate change on the already marginalized community of fisher folks in Kerala, a part of South India. State Government initiated a project termed as “*Theeramythri*” a program that encourages, facilitates and handholds fisherwomen to engage in gainful alternate self-employment for their economic and social emancipation. Climate changes may affect fisheries directly by influencing fish stocks and the global supply of fish for consumption, or indirectly by influencing fish prices or the cost of goods and services required by fisher folks. We have interviewed 465 woman in three regions, where the project *Theeramythri* is being implemented, in Trivandrum, Kochi, and Kerala respectively. We also examine the threats posed by climate change to the traditional ‘economy’ of fishing. In order to maintain, economic, cultural and social benefits of fisheries in the face of climate change, planned adaptation at scales from the local to the regional is required. We use the concept of resilience in linked social-ecological systems to examine how such responses may be developed and promoted. Key strategies include facilitating people's geographical and occupational mobility, improving inter-sectoral tradeoffs of goods and services, and promoting forms of co-operations envisaged by the “*Theeramythri*” that help build resilience of systems. It is recommended that increased and sustained investments in market, and governance are crucial in order to minimize the potential impacts of climate change on fisheries.

**June 6, 14:20/S15-Oral-12717**

### **Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands**

Johann D. **Bell**, Andrés Cisneros-Montemayor, Quentin Hanich, Johanna E. Johnson, Patrick Lehodey, Bradley Moore, Morgan S. Pratchett, Gabriel Reygondeau, Inna Senina, John Virdin and Colette Wabnitz

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In several Pacific Island countries and territories (PICTs), rapid population growth and inadequate management of coastal fish habitats and stocks is causing a gap to emerge between the amount of fish recommended for good nutrition and sustainable harvests from coastal fisheries. The effects of ocean warming and acidification on coral reefs, and the effects of climate change on mangrove and seagrass habitats, are expected to widen this gap. To optimise the contributions of small-scale fisheries to food security in PICTs, adaptations are needed to minimise and fill the gap. Key measures to minimise the gap include community-based approaches to: manage catchment vegetation to reduce sedimentation; maintain the structural complexity of fish habitats; allow landward migration of mangroves as sea level rises; sustain recruitment and production of demersal fish by managing 'source' populations; and diversify fishing methods to increase catches of species favoured by climate change. The main adaptations to help fill the gap in fish supply include: transferring some fishing effort from coral reefs to tuna and other large pelagic fish by scaling-up the use of nearshore fish aggregating devices; developing fisheries for small pelagic species; and extending the shelf life of catches by improving post-harvest methods. Modelling the effects of climate change on the distribution of yellowfin tuna, skipjack tuna, wahoo and Mahi mahi, indicates that these species are likely to remain abundant enough to implement these adaptations in most PICTs until 2050. We conclude by outlining the policies needed to support the recommended adaptations.

**June 6, 14:40/S15-Oral-12643**

### **Seafood security strategies in China**

Cody **Szuwalski**<sup>1, 2</sup>, Jin Xianshi<sup>3, 4</sup>, Shan Xiujuan<sup>3, 4</sup> and Tyler Clavelle<sup>2</sup>

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China has implemented a multi-faceted approach to seafood security, including aquaculture, wild-capture fisheries, stock enhancement, and artificial habitat construction on an unmatched scale. We identify drivers of seafood production and interactions between production modes by province. China's ocean 'experiments' suggest large biomasses of captured fish are possible, but this strategy is only viable if markets exist for small fish and comes at a cost of compressed ecosystems, a loss of larger organisms, and potentially risks resilience under a changing climate. Aquaculture can greatly increase seafood production, but the relationship between area and produced biomass varies by product and province, sudden crashes have been observed, pollution and disease can be problematic, and sourcing feed from wild-capture fisheries may exacerbate overfishing. In China, increased culture of shellfish and algae was often positively correlated with catch per unit effort (CPUE) in fisheries; increased culture of crustaceans was often negatively correlated with CPUE. Given observed tradeoffs, strategies for seafood security in China should be developed at the ecosystem level and carefully consider the current, projected, and desired state of the ecosystem and related markets. We discuss the potential effects of climate change on China's current seafood strategy.

**June 6, 15:00/S15-Oral-12974**

### **Adapt or lose: How to manage the socioeconomic impact of climate change in the Spanish aquaculture, the case of blue mussel**

Mariola **Norte**<sup>1,2</sup>, Rosa Chapela<sup>1</sup>, Jose L. Santiago<sup>1</sup>, Marta Ballesteros<sup>1,2,3</sup> and X. Antón Álvarez-Salgado<sup>4</sup>

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In the context of the ecosystem approach for aquaculture, the climate change is gaining relevance because its direct effects on the primary productivity but also for its indirect effects on the livelihoods of the communities related. In this paper, we propose a stepwise framework to improve the understanding of these effects in a community dependent on mussel cultivation (i.e. aquaculture) and how it supports the decision-making of management and production strategies. Climate change affects flesh yield and harvesting time of mussels as well as the occurrence of harmful algal blooms, which impact on their output. These effects have a direct influence on the mussel sector but also on the stakeholders who provide inputs to this aquaculture sector (backward) as well as to those who use mussels as an input for their production (forward). These spill over effects can be traced and estimated on the basis of the input-output analysis but also involving the stakeholders related. The preliminary results show how this analytical framework provides an accurate assessment of the socioeconomic impacts caused by the climate change by considering the backward and forward effects simultaneously. The proposed framework improves the decision-making process, in particular its capacity to anticipate the effects of climate change by comparing in advance different scenarios. Therefore, the sectors and communities are able to react and propose adaptation and mitigation strategies in a participatory way, enhancing more holistic and sustainable management systems.

**June 6, 15:20/S15-Oral-13125**

### **Strategies for diversifying Maine's softshell clam fishery in response to climate change**

Ethel **Wilkerson**, Marissa McMahan and John Hagan

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In Maine (USA), the softshell clam (*Mya arenaria*) fishery generates about \$15 million in landings each year and has long been vital to rural, coastal communities. However, the Gulf of Maine is warming at a rate faster than 99% of the world's oceans, and warmer waters have brought increased predation of softshell clams from the invasive European green crab (*Carcinus maenas*), widespread algae blooms causing clam mortality, and more frequent closures due to red tide conditions. The once lucrative softshell clam industry is in dramatic decline. Alternative strategies are needed to diversify harvesters' income in this time of great ecological change. All potential strategies must be compatible with the co-management of this fishery by state and municipal governments, which gives harvesters and communities management authority over the industry. We are working with shellfish harvesters to field-test three strategies: 1) intertidal aquaculture for softshell clams that reduces predation of green crabs and helps restore unproductive flats, 2) aquaculture for quahogs (*Mercenaria mercenaria*), a species whose range is shifting northward as water warms, and 3) developing a Green crab fishery that utilizes an invasive species as value-added products. All of these alternatives are compatible with small-scale, community-focused aquaculture: local harvesters manage the operations and residents provide input on the type and location of aquaculture that occurs within their community. Our study will report on the biological, economic and social outcomes of these strategies designed to strengthen the viability of the softshell clam fishery and provide diversified opportunities for softshell clam harvesters.

**June 6, 15:40/S15-13232**

### **Climate variability and fisheries: tools and information requirements**

Anne **Hollowed**<sup>1</sup>, Jim Salinger<sup>2</sup>, Keith Brander<sup>3</sup>, Karen Evans<sup>4</sup>, Andrew Nkansah<sup>5</sup> and Robert Stefanski<sup>6</sup>

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The World Meteorological Organization joint task team involving two technical commissions was established to pursue the understanding of the impacts of climate change on fisheries and marine aquaculture, and to identify risk assessment and management evaluation tools that incorporate climate variability in order to improve the ecosystem-approach to management of fisheries. Climate change imposes a new set of pressures on marine ecosystems; increasing temperature, reduced salinity in some enclosed seas and coastal areas, changing wind fields and seasonality, acidification, deoxygenation and rising sea level all affecting marine life. Climate variability is one of the dominant signals in open ocean systems. The production patterns in many oceanic fisheries have been linked to variability from on various time scales owing to such features as ENSO and the PDO. Scientists have embarked on an ambitious effort to project the risks of climate change to marine fish and fisheries and to develop simulation tools to assess the performance of different management strategies to sustain fisheries under changing ocean conditions. The Global Forecasting of Climate Services (GFCS) is developing effective partnerships and dialogue between climate services and fishers at all levels. Key observations of variables required for predictions of a season to a year include: SST, sea ice extent, upper ocean heat content, soil moisture, snow cover, and state of surface vegetation over land are all important. As intra- and inter-seasonal variability impacts significantly on fisheries and aquaculture, inputs from the fishing sector will be crucial in developing new products.

**June 6, 16:20/S15-Oral-13035**

### **Accounting for shifting distributions and changing productivity in the development of scientific advice for fisheries management**

Melissa A. **Karp**, Jay Peterson, Patrick Lynch and Roger Griffis

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There is a clear need to increase the production, delivery, and use of information and tools to address the impacts of changing ecosystems on living marine resources. There is growing evidence of climate-related effects on species distributions and productivity, and these effects are expected to increase with continued changes and increasing variability in climate and ocean systems. Shifting distributions and productivity can present a variety of challenges to effective fisheries management. In 2017, the U.S. National Marine Fisheries Service (NOAA Fisheries) created a national working group comprised of scientists and other experts to identify specific issues, needs, and recommendations to better understand and respond to shifting species distributions and changing productivity throughout the science-to-management process. This presentation describes that process and draft recommendations including, developing more flexible and adaptive monitoring programs for tracking species distributions, prioritizing mechanistic research, increasing the use of spatio-temporal and geostatistical modelling, strengthening the use of ecosystem indicators and assessments, standardizing the process by which results are communicated to managers, and increasing the evaluation of management strategies under projected future ocean scenarios. Successful implementation of these recommendations will better position NOAA and its management partners to address the growing challenges of managing U.S. fisheries in a changing climate.

**June 6, 16:40/S15-Oral-13051**

## **Climate-related impacts on fisheries management and governance in the Northeast Atlantic**

Erin Priddle<sup>1</sup>, Jessica Landman<sup>1</sup>, Kristin Kleisner<sup>1</sup>, Merrick **Burden**<sup>1</sup> and Katrina Ryan<sup>2</sup>

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It is well documented that climate change is impacting on the range, distribution and productivity of key commercial species in the Northeast Atlantic region. Although Europe operates within a relatively robust governance system, with high levels of information flow between actors and coastal states, the response to these climate-driven changes are not keeping pace. Tools and approaches are available, but their application lags behind. Regional institutions are straining to deal with the challenges of shifting stocks, particularly given requirements to implement the EU-wide Landing Obligation under rigid EU quota allocation rules, making alignment of catch and quota in a dynamic ecosystem challenging. This combination has the potential to create a 'perfect storm' - compromising the ecological and socio-economic integrity of the region. Environmental Defense Fund (EDF) set out to explore the implications of these profound shifts through a workshop attended by climate and fisheries scientists and policy experts from across the region. The workshop report explores core governance challenges presented by climate change through the lenses of 'science', 'management', and 'institutions'. We learned that Europe has the ability to achieve adaptive fisheries management and governance, building resilience through the adoption of durable management strategies and regionally-appropriate tools and approaches. This will require a) greater inclusivity in decision-making to help bridge the gap between science and policy disciplines, b) re-invigorated regional institutions that support improvements to existing straddling stock agreements, and c) a shift toward more ecosystem-based fisheries management (EBFM) suitable for managing multiple, interacting and transboundary stocks.

**June 6, 17:00/S15-Oral-13167**

## **Adapting to climate change in the Pacific Islands: Nutritional impacts of a change in pelagic fish consumption**

Colette **Wabnitz**<sup>1</sup>, Louise Teh<sup>1</sup>, Joelle Albert<sup>3</sup>, Joey Bernhardt<sup>1</sup>, Tiff-Annie Kenny<sup>2</sup>, Mechthild Kronen<sup>4</sup>, Franck Magron<sup>5</sup> and William W. L. Cheung<sup>1</sup>

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In many coral reef countries, growing demand for fish, depleted coastal fisheries resources, and climate change impacts threaten future food security. This is particularly relevant for Small Islands States throughout the Pacific where 50–90% of the animal-sourced protein consumed among rural populations comes from mostly reef fish. It is suggested that within 15 years an additional 115,000 tonnes of fish will be needed across the Pacific region for good nutrition. To help fill this gap recent studies have recommended an increase in the consumption of tuna from industrial fisheries and small-scale fishing around Fish Aggregating Devices, as well as an increase in the intake of small pelagics. While the sustainability implications of a shift from inshore to offshore fisheries has been considered, the health implications of a shift towards greater consumption of pelagic fish remain unknown. This study investigates the nutritional implications of increased consumption of pelagic species vs inshore reef species in a number of Pacific Island Countries and Territories. Specifically, we assess the nutritional and health impact in terms of protein, mercury, essential fatty acids and micronutrient intake from such a shift in consumption habits. We make suggestions in terms of the quantity and types of fish that would contribute to a nutritious diet and support individuals' needs to balance food security and nutrient adequacy. This study's results provide important information to jointly promote ecosystem and human health in a rapidly changing environment with important implications for policies on health, food security, and fisheries sustainability.

**June 6, 17:20/S15-Oral-13225**

## **Risks and opportunities of climate change to European fisheries and aquaculture sectors: The CERES Program**

Myron **Peck**<sup>1</sup>, Ignacio Catalan<sup>2</sup>, Mike Elliott<sup>3</sup>, João Ferreira<sup>4</sup>, Pauline Kamermans<sup>5</sup>, Susan Kay<sup>6</sup> and John Pinnegar<sup>7</sup>

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This presentation summarizes the main findings from the first two years of CERES, a four-year project funded by the European Union's Blue Growth program to explore the effects of climate change (CC) on Europe's most valuable fish and shellfish resources and aquaculture and fisheries sectors. Important differences exist in the potential effects of climate change on Europe's marine regions such as the Barents, North, Baltic and Mediterranean Seas. Downscaled, biogeochemical model projections for RCPs 4.5 and 8.5 are now available for most regions and these are dovetailed with PESTLE (political, economic, social, technological, Legal, Environmental) scenarios when conducting biological and economic modelling of CC impacts. CERES takes a participatory approach and, to date, has conducted >50 regional or Europe-wide engagement events with stakeholders from the aquaculture and fisheries sectors and policymakers. A gap analysis of 400+ studies on the direct effects of CC on European fish and shellfish resources highlighted a lack of knowledge on stage-specific impacts of interacting factors (e.g. warming, acidification and hypoxia) on most fish and shellfish. New experiments were conducted to fill some of these gaps and to better parameterize biological projection models for several species. This ambitious project has 26 "storylines" (region-, sector- and species-specific activities) and we highlight recent results from several marine storylines, providing concrete examples of how ocean physics, ecophysiology, economics and social science are being combined in the climate science conducted by CERES to create bottom-up (industry driven) and top-down (policy) solutions for Europe's fisheries and aquaculture sectors.

**June 6, 17:40/S15-Oral-13240**

## **Methods and tools for fisheries and aquaculture adaptation**

Florence **Poulain**<sup>1</sup>, Amber Himes-Cornell<sup>1</sup> and Clare Shelton<sup>2</sup>

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Under the United Nations Framework Convention on Climate Change (UNFCCC, governments have committed to support and/or implement adaptation efforts. Current knowledge of available adaptation tools and methods to adapt to climate change in the fisheries and aquaculture sectors is fragmented across disciplines. This study aims to fill this gap and illustrates the range of tools and methods available to governments, industries and individual fishers/fish farmer with a view to improving understanding of adaptation and guide actions and policies. Adaptation efforts can be distinguished according to their intent (autonomous or planned), their timing (reactive, concurrent or anticipatory), the scale at which they occur (including farm, watershed, nation and/or region), the responsibility of various stakeholders (fishers, fish farmers, industry, and governments), the degree of necessary change (incremental, transformational), or their form. Differentiating responses to climate change according to form provide a useful framework to understand adaptation in the fishery and aquaculture sector. This study groups adaptation tools and methods according to three main categories that are not mutually exclusive: (1) institutions and management, (2) livelihoods, and (3) risk reduction and resilience. This typology does not attempt to recommend or prescribe specific adaptations. It recognizes that effectively meeting adaptation objectives will involve a spectrum of options – implemented by public institutions or the private sector – within an existing governance framework. The study draws on practical examples, methods and tools from fishery and aquaculture management but also from risk management, decision-making and economics of adaptation. Specific attention is given to adaptive capacity of developed countries and small-scale fishers/fish farmers. This study will contribute to informing the integration of fisheries and aquaculture into the nationally determined contributions and the development of national adaptation plans of governments.

## **S16: Climate, Oceans and Security**

**June 4, 11:35/S16-Invited-12593**

### **Geopolitical Implications of Arctic Warming**

Frances A. Ulmer

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My presentation will focus on the Arctic region. I will discuss the security implications of climate and oceanographic changes in the North, itself, as well as long-range impacts of the Arctic on other parts of the globe. Because the Arctic region is warming at twice the global average, a formerly white ocean is turning blue. For example, the spatial coverage of floating sea ice in the Arctic Ocean has diminished by more than 50% over the past 30 years and the volume of sea ice has diminished by 75% in summer. This “opening” of a new, northern ocean impacts the geopolitical interests of not only the eight Arctic nations, but others, as well, in Asia and Europe. The new ocean provides greater opportunities for expanding marine activities, such as fishing, oil and gas exploration and development, destinational and trans-Arctic shipping, tourism, and scientific research. The increasing accessibility of the Arctic region also has major implications for national security interests, starting with domain awareness. Other changes in the Arctic have direct impacts on the lower latitudes, where the majority of the global population lives. For example, the increasing melting rate of glaciers and the Greenland ice sheet, contributes to sea level rise, globally which will challenge many coastal communities. The resulting national security concerns include exacerbated societal instabilities, human migration, degradation of critical military infrastructure, and compromised operational readiness.

**June 4, 12:05/S16-Oral-12376**

### **Security at the top of the world: Arctic change and new governance**

Lawson W. Brigham

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The Arctic Ocean’s sea ice cover is undergoing a profound transformation. The observed retreat in extent and thickness, and changes in ice age provide greater marine access and potentially longer seasons of navigation throughout the Arctic Ocean. A significant driver is globalization of the Arctic – the linkage of Arctic natural resources to global markets – which is creating a need for new marine transportation systems. Such increasing Arctic marine use has spurred close cooperation among the Arctic states and within the maritime community in framing a new era of governance for the maritime Arctic. UNCLOS remains the legal framework as advanced by the 5 Arctic Ocean coastal states in its Ilulissat Declaration (2008). The Arctic states have negotiated two binding agreements: the Arctic SAR Agreement (2011), and the Arctic Oil Spill Preparedness and Response Agreement (2013); the Arctic states have also formed an Arctic Coast Guard Forum to address maritime issues. The International Marine Organization has negotiated a Polar Code for ships operating in polar waters, a new international governance regime for commercial shipping. All of these initiatives, including an ongoing effort to develop an agreement for fishing in the central Arctic Ocean, point to greater cooperation and stability in the region. A review of the challenges and uncertainties for marine infrastructure development, seasonal shipping routes, and evolving marine safety and environmental protection measures will be presented.



**June 4, 12:25/S16-Oral-13098**

**National security implications from tipping events centered in Arctic waters**

Diana **Bull**<sup>1</sup>, Kara Peterson<sup>1</sup>, George Backus<sup>2</sup>, Jasper Hardesty<sup>1</sup> and Amy Powell<sup>1</sup>

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Large changes in natural system states (desertification, disruption to Gulf Stream circulation, etc.) with high societal impacts are known as tipping events. These events are often accelerated by feedbacks within a system and must be considered holistically from dynamical instantiation through to resultant natural and socio-economic impacts to appreciate their full influence. Arctic systems are strongly coupled and rapidly changing, and are believed to be driving towards a number of possible tipping events with the potential for disrupting the Earth climate system. In a recent article highlighting policy-relevant tipping elements in global climate, the majority were intrinsic to Arctic waters (ocean and ice) and included disruption of the Atlantic thermohaline circulation, loss of Arctic summer sea ice, Greenland ice sheet melt, and release of marine methane hydrates. This talk will explore the approach we are taking to understand the full system implications of tipping events originating in the Arctic. This comprehensive orientation is designed, in part, to identify global national security risks emerging from tipping events centered in Arctic waters. Given the number of variables influencing the tipping event and the resultant natural and socio-economic changes, the role of uncertainty in these predictions is paramount. Alternative views focusing on uncertainty as the driving force for understanding national security risk and preparedness will be presented.

**June 4, 14:00/S16-Oral-12763**

**Connecting Earth system models to national security decision-making: Examples, opportunities and research needs**

Todd **Ringler**, James Cooley, Eric Dors, Jeanne Fair, Matt Heavner, Elizabeth Hunke, Joel Rowland, Nathan Urban and Cathy Wilson

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Earth system models are the primary tool for assessing future impacts of greenhouse gas emissions on the global and regional environments. While ESMs have always had some connection to national security, this connection has been weak, uneven and distant. Advances in the fidelity and comprehensiveness of ESMs, along with the continued merging of ESMs with weather prediction, now enable this capability to make direct and substantive contributions to a wealth of national security issues.

This talk will present four situations where ESMs are poised to inform national security decision-making: a summertime ice-free Arctic, the role of extreme events in driving vector borne infectious disease, refining the likelihood of abrupt sea-level rise, and quantifying the impact of changing environmental conditions on water scarcity. The examples are chosen not only based on the likelihood of near-term success, but also to highlight the diversity of situations where this predictive capability can be useful. In addition, each example is used to emphasize distinct research needs that are required to mature and optimize the capability.

While the examples are applicable to any of the two dozen ESMs in use around the world, this presentation will primarily make use of the Department of Energy's ESM in building out the four examples.

**June 4, 14:20/S16-Oral-12947**

**Extension of the ecosystem based management scale in the face of climate change: Cosmic perspective and need to respect the basic principle of peacekeeping**

Amrtatjuti V. **Sereda**

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It is now obvious, according to past data on Earth's tectonic activity and large variations in planetary surface temperature over timescales of many thousands (even millions) of years, that the Earth's global climate change and ocean conditions are determined not only by internal factors but also by cosmic factors. These include, but not limited to, the moving of the solar system around the center of our galaxy, the cyclic variations of solar activity, the variations of cosmic energy accumulation and distribution in our solar system, solar wind, cosmic rays, space dust. From this it follows that cosmic factors may have a big influence on the nature management in particular on marine resource use. On the other hand, this gives a strong reason for convergence of the national *interests of States as mutually enhancing structural elements of the developing world order by developing* integrated Marine Spatial Plans facing up to the inescapable reality that the world's security had come to depend on the cosmic-ecosystem sustainability, an objective assessment by States of their national prospects in the key of the Climate Change *and respect the basic principle of peacekeeping by international community*. We discuss the extension of the ecosystem based management scale in the frame of cosmic-ecosystem based management by taking into account factors originating in space and by increasing the participation of international stakeholders in Marine Spatial Planning for building cooperative marine environmental protection regimes and achievement long-term sustainability in the world regions.

**June 4, 14:40/S16-Oral-12368**

**Fisheries, climate change and human insecurity in the Niger Delta area of Nigeria**

Ifesinachi Marybenedette **Okafor-Yarwood**

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Fisheries contribute to the food security of more than three billion people globally. In Nigeria, it accounts for up to 80% of the animal protein and sometimes the only source of animal protein available to littoral communities such as those in the Niger Delta area of Nigeria. It also contributes to the revenue of the country, with Nigeria's earnings from the exportation of shrimps estimated at \$29 million in 2015. However, the pervasiveness of unsustainable practices that are harmful to the marine environment such as pollution, illegal, unreported and unregulated (IUU) fishing, coupled with the extreme impact of climate change threatens the human security of fisher folks and their families who depend on fisheries for subsistence. This paper seeks to explore some of the human security implications – with emphasis on the food security – of climate change in contributing to the depleting marine resources for fishing settlement in Bonny Island in the Niger Delta area. The paper will show that for a region that has been significantly impacted by pollution and unsustainable fisheries practices such as IUU fishing, the impact of climate change exacerbates an already debilitating situation. In response to the perceived threat to their security, some of these fisher folks and fish mongers (who are predominantly women), engages in actions that might be deemed as illegal in order to make ends meet.

**June 4, 15:00/S16-Oral-12708**

**Strained stability: Climate change and regional security in the Asia Pacific**

Esther **Babson** and Andrew Holland

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Climate change acts as a threat multiplier, exacerbating existing risks and undermining national and global security. The effects of climate change will undermine various measures of human security, and could catalyze new, dangerous intercommunal conflicts. One area of particular danger is in South East Asia and Oceania. Warmer ocean temperatures and melting polar ice caps will cause sea levels to rise, while extreme weather becomes more frequent and extreme, leading to increased flooding and in some cases complete submergence of coastal communities and infrastructure throughout the region. In addition, changes in ocean temperature and acidity will

cause coral reefs to die off and fish distribution to change. The most recent IPCC assessment ([https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap24\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap24_FINAL.pdf)) highlights how the region is heavily dependent on fish production with 85.5% of the world's fishers and fish farmers in Asia. Put together, these impacts would decimate livelihoods, destroy communities, and drive both internal and cross-border migration. If not managed correctly, such displacement can cause severe civil stress and conflict, even undermining state stability. Outside military forces could be called upon to restore order or put down uprisings. This study will delve into the direct impacts of climate change in South East Asia and Oceania, the potential socio-economic effects, and resulting security risks.

**June 4, 15:20/S16-Oral-12567**

### **Building resilience of coastal communities to natural disasters**

Ayse Sezin **Tokar** and Curtis B. Barrett

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Globally, disasters related to storms including hurricanes, cyclones and storm surges claimed over 240,000 lives, affected 600 million people and cost over one trillion USD during 1995-2015. Storms combined with exposure, vulnerability, and low coping capacity lead to loss of lives, destruction of livelihoods, property and displacement in addition to impacts on people's health and socioeconomic wellbeing. Healthy oceans, seas and marine resources are critical in reducing disaster risk in coastal areas. The degradation of natural barriers such as sand dunes, wetlands, and coral reefs due to unsustainable use and coastal erosion combined with intense and frequent weather extremes and sea level rise could put millions of people at risk of coastal hazards. Currently more than half of the world's population lives within 60 miles of the coastlines. The proportion of the world's population living on cyclone-exposed coastlines has increased two-fold over the last three decades. As encroachment of settlements in coastal areas expands along with sea level rise, exposure and vulnerability to coastal hazards such as cyclones and tsunamis will increase. Lives, livelihoods, assets, and investments lost to disasters and the costs of disaster response, compensation, and rebuilding will constitute a heavy burden on communities and governments. We will present how USAID/OFDA works at all levels to reduce impacts of coastal hazards on people's lives and livelihoods in partnership with many countries, regional organizations, NGOs, USG, UN and others. Examples will include hazard early warning systems, disaster preparedness, providing access to information and community based activities.

**June 4, 15:40/S16-Oral-12951**

### **Ocean research to improve climate system understanding and support national security decision-making**

Apurva **Dave**

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Ocean research is crucial for understanding, assessing and predicting climate variability and change, and for elucidating the role of the oceans within the larger climate system. The knowledge that is gained directly supports our responses to climate impacts on a range of societal issues, including national and international security. The current configuration of ocean observing systems, process studies and modeling, however, cannot address the full range of scientific and societal issues related to security. This talk will provide a summation of the Session by examining the challenges and opportunities for ocean research, in the context of answering major science questions and addressing the impacts of anthropogenic and natural processes of climate variability and change on security.

## **S17: Effects of climate change on ocean ecosystem health: Projecting occurrences of harmful algal blooms and disease outbreaks and assessment of the risk to ecosystem functioning, aquaculture, fisheries and human health**

**June 7, 11:10/S17-Invited-13237**

### **Recurrent green tides in the southern Yellow Sea: The process, drivers and way forward**

Xuelel **Zhang**<sup>1</sup>, Zongling Wang<sup>1</sup>, Jie Xiao<sup>1</sup>, Rongguo Su<sup>2</sup>, Songdong Shen<sup>3</sup>, Wei Hu<sup>4</sup>, Qinqin Lu<sup>5</sup> and Junwei Shan<sup>6</sup>

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The green tides, blooms of green macro-algae, have been recurrent every late spring since 2007 in the southern Yellow Sea. We present the process and trend of these green tides, largest ones in the world sea waters. The major causal species has been identified as *Ulva prolifera*. Our studies have been resolving the biological and ecological drivers of these green tides. With the findings and technologies developed, national monitoring and early warning system has been setup and functioning. Advancement of new methods are underway to prevent onset, control the extension of the green tides, and to transform and utilize the huge algal biomass. With these science and technical support to the concert efforts from related sectors, we project that the largest green tides in the world would be effectively abated and eventually controlled.

**June 7, 11:40/S17-Oral-12676**

### **Effects of meteorological factors on the temporal distribution of red tides in Tolo Harbour, Hong Kong**

Jiansheng **Huang**<sup>1,2,3</sup>, Hao Liu<sup>1,2</sup> and Kedong Yin<sup>1,2</sup>

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Red tides represent a major environmental issue in coastal waters globally. However, few studies have examined the relationship between red tides and meteorological factors. Thus, we used a 32-year time-series of frequent red tide events in Tolo Harbour and Channel, to study their relationship with meteorological factors. Most red tides are dominated by dinoflagellates in March, while most diatom red tides in May. Dinoflagellate and diatom red tides respond differently to different meteorological factors. Warming air temperatures in spring favor the generation of dinoflagellate red tides, while precipitation hinders them. The optimum temperature range is approximately 17–23°C and 26–29°C for dinoflagellate and diatom red tides, respectively. Moderate northeasterly winds promote the formation of dinoflagellate red tides. Dinoflagellate red tides are not hindered by cloudy weather and occur in sunlight of varying brightness, whereas diatoms red tides require a certain amount of bright sunlight.

**June 7, 12:00/S17-Oral-12804**

**Can we track climate related changes in the HAB species assemblage in a highly variable coastal sea (Gulf of Trieste, Adriatic Sea)?**

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Population dynamics of HAB species has been followed since 1995 in the frame of the monitoring programme at mussel farms in the Gulf of Trieste. Although the sampling scheme and methods have been subjected to modifications during these two decades, a comparison of the data revealed a quite stable seasonal occurrence of the most abundant HAB species. For example, seasonal peaks of some recurrent *Dinophysis* species occur in a predictable pattern, while their abundances show significant year-to-year fluctuations, which are in line with the notorious variability of environmental characteristics in the Gulf of Trieste. These peaks are driven by specific environmental factors of which low salinity and persistent stratification seem to be the most important. The evolution of both factors can be perhaps ascribed to climate linked changes, like deviations in circulation pattern and enhanced/reduced river discharges. A particular case of such condition was observed in the 2010, when an unusually long persistence of some toxic *Dinophysis* species in the sea water led to extended closure of shellfish harvesting. Also the phenomenon of newly emerging HAB species, which were never (or very rarely) recorded in the area before, but are in the last few years becoming recurrent, may be related to climate driven north expansion of species. One of these is *Dinophysis tripos*, which was first observed in 2010 and is since occurring every autumn. The other peculiar species is *Karenia papilionacea*, with first comparison in autumn 2015 and rising abundances up to 300 cells/L in spring 2017.

June 7, 12:20/S17-Oral-12905

## Regional changes in harmful algal events in the North Atlantic area over the last two decades documented using the HAEDAT database

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The International Council for the Exploration of the Sea (ICES) - Intergovernmental Oceanographic Commission of UNESCO (IOC) Working Group on Harmful Algal Bloom Dynamics (WGHABD) has entered data into the Harmful Algal Event (HAEDAT) database for the last 20 years. These entries report information about harmful algal events that result in management actions such as closures of shellfish harvesting areas or negative environmental impacts e.g. mortalities of marine mammals. These data, collected mainly from routine monitoring programmes, provide a wealth of information that is not routinely accessible for scientific assessment. WGHABD is producing a HAB status report based on the incidence of HAB events in the ICES area which will contribute to a Global HAB Status Report. These HAEDAT data reveal a regional distribution in harmful algal events in the North Atlantic area. On the east coast of the USA and Canada, the majority of issues have been caused by paralytic and amnesic shellfish poisoning toxins (PSP, ASP). In contrast, diarrhetic shellfish poisoning (DSP) has been the dominant cause of problems in Europe while cyanobacteria events were restricted to the Baltic. HAEDAT also provides information about changes in the incidence of harmful algal events over time e.g. the recent increased recording of DSP events in the USA, a reduction in the incidence of PSP closures in Scottish waters at the beginning of this century. HAE-DAT is an essential source of information to support investigation of environmental drivers such as climate change on the incidence of harmful algal events on a regional scale.

June 7, 14:00/S17-Oral-13146

## **GlobalHAB: International coordination to ascertain the effects of Climate Change on the occurrence of Harmful Algal Blooms**

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The Global Harmful Algal Blooms (GlobalHAB) Programme is an international scientific programme on harmful algal blooms (HABs) aimed at fostering and promoting cooperative research directed toward improving the prediction of HAB events, and providing sound knowledge for policy- and decision-making to manage and mitigate HAB impacts in a changing planet. GlobalHAB is sponsored by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR).

GlobalHAB identified climate change as an important driver on HAB occurrence and impacts and highlighted specific objectives and actions to predict these events in a changing ocean.

Among others, it is necessary to improve the fundamental understanding of the responses of microalgae to climate-linked drivers of HABs (thermal windows, stratification, changing levels of CO<sub>2</sub>). This challenge needs to be addressed by experimental work and field observations, which in turn require adoption of best practices approaches to investigate HAB responses to climate-linked drivers. It is also necessary to establish solid baseline information on biodiversity and biogeography of harmful taxa that requires consistent and long-term data series at local and regional levels and exploring paleoceanographic records as well. New modelling capabilities will also help to project the response of HAB species to climate change scenarios.

Addressing these objectives and actions will benefit from international research cooperation fostered by GlobalHAB also aligned with other international programmes and initiatives such as GOOS (Global Ocean Observing System) and the ICES-IOC Working Group on Harmful Algal Bloom Dynamics (WGHABD).

**June 7, 14:20/S17-Oral-13192**

### **Solving harmful algal blooms problems by organizing bricks: *Ostreopsis* blooms as an example**

Rafael Abós-Herràndiz<sup>1</sup>, Magda Vila<sup>2</sup> and Elisa **Berdalet**<sup>2</sup>

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Harmful algal blooms (HABs) are complex phenomena, caused by both natural and anthropogenic forcings with impacts on human health and wellbeing. HABs can be conceived as a Jungian Mandala composed by multi-connected bricks. Solutions to mitigate the negative effects of HABs can be found by identifying the different “Mandala building bricks”, their twofold cause and solution roles and, the connections among them. Two main kinds of bricks are at play: the natural dynamics of the microalgae in the habitat and the different human actors including directly affected end users, forcing activities, health systems, scientists, funders, policy makers and mass media. Identification of the Mandala building bricks determines their appropriate monitoring and helps to prioritize prevention and mitigation of the impacts of HABs, and ideally their occurrence. In this presentation we will show this approach applied to the particular case of *Ostreopsis* blooms. Human intoxications due to aerosol inhalation in certain Mediterranean beaches affected by *Ostreopsis* presence and/or proliferations have been reported in the last two decades. This benthic genus of tropical origin seems to be spreading to temperate waters likely due to a combined global warming and human activities. *Ostreopsis* produces palytoxin (PITX), related to dramatic seafood intoxications in the tropics, luckily not documented in the Mediterranean yet. Building the *Ostreopsis* Mandala will help to promote local to global governance of the problem.

**June 7, 14:40/S17-Oral-13217**

### **Which species traits predict susceptibility to disease in warming oceans? A systematic review of the literature from natural and aquaculture systems**

Alexandra **Campbell**

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Disease is emerging as a major threat to marine biodiversity and function in natural habitats and is responsible for a 40% decrease in the capacity of aquaculture production globally. Disease is likely to become more frequent and severe in marine ecosystems, due to rapidly changing environmental conditions, however we currently lack the ability to predict when, where or why certain organisms, habitats or locations might be at particular risk. I conducted a systematic review of the literature to assess whether marine organisms that are reported to suffer from disease outbreaks share certain characteristics relating to their phenomes, genomes or microbiomes. Organisms from natural ecosystems and aquaculture settings are included and traits associated with disease resistance and disease susceptibility are identified. The results will be discussed in the context of ‘future-proofing’ key habitats, organisms and industries. Specifically, I will discuss whether trait-based approaches can facilitate identification of particularly vulnerable organisms, habitats or locations in need of additional research and targeted protection and management. Additionally, I will point to certain traits that may help with restoration and strain selection programs to ‘future-proof’ key habitats, ecosystem services or aquaculture industries.



June 7, 15:00/S17-Oral-13014

### Applying a dynamic energy budget model to understand nematode parasite influence on the trade-offs between reproduction and energetic condition of fish

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It is commonly assumed that parasites benefit at the expenses of their host in a non-mutual relationship, in which parasites effect the health and survivorship of their hosts by either draining host energy resources through consumption and energetic cost of immune defences or altering behaviour, tissues or physiological processes. However, through the coevolution, the effects of parasites on their hosts results on a balance between the benefits of exploiting the hosts resources and the costs of harming them. In a context of climate change, environmental alterations can unbalance these historically established relationships affecting hosts growth, energetic condition, reproductive capacity and ultimately, natural mortality rate. Fish infection by nematode endoparasites have received great attention, especially in exploited species, due to their high prevalence and the fact that some anisakid nematodes may cause human diseases, but little research has been done on their effects on fish life history traits. Here we developed a model of dynamic energy budgets (DEB) to analyse the effects of nematode parasite community on the reproductive potential, energetic condition and the trade-offs between these parameters and, subsequently, we applied it to Blue whiting (*Micromessitius poutassou*) from the NW Mediterranean Sea, a cold-water fish species inhabiting a warming sea, as case study. Results are of great relevance because the developed model allows to predict future deleterious effects of the parasites on their hosts under climate change projections, which ultimately have strong implications for fish stock productivity, fisheries management and food security.

June 7, 15:20/S17-Oral-12861

### Three species of *Vibrio* pathogen in the Chesapeake Bay under future climate change scenarios

Barbara **Muhling**<sup>1,2</sup>, John Jacobs<sup>3</sup>, Charles Stock<sup>4</sup>, Carlos F. Gaitan<sup>5</sup>, Vincent Saba<sup>6</sup>, Desiree Tommasi<sup>1,2</sup>, Keith Dixon<sup>4</sup> and Fernando Gonzalez-Taboada<sup>4,7</sup>

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Bacteria in the genus *Vibrio* can cause illness to people through eating of contaminated seafood, or exposure to contaminated water, incurring significant healthcare costs. *Vibrios* occur naturally in the Chesapeake Bay, but their abundance varies with water temperature, salinity and other factors. We assessed the potential effects of climate change on the future abundance of three *Vibrios* in the Chesapeake Bay: *V. vulnificus*, *V. parahaemolyticus*, and *V. cholerae*. Relationships between each species and environmental conditions were obtained from published predictive habitat models. Projections of future water temperature and salinity in the Bay were derived from four general circulation models, which were statistically downscaled to the spatial extent of the Chesapeake Bay and Susquehanna River watershed. We show that abundance of *Vibrios* in the water column, and in oysters, is likely to increase as temperatures warm and flow regimes change. Water temperature was most influential in determining probability of occurrence in the water column, while salinity was important for defining spatial areas of highest risk within the Bay. In addition, the seasons of highest risk may last longer for both *V. vulnificus* and *V. parahaemolyticus*, compared to the present day. Results therefore suggest that *Vibrio*-related illnesses in the Chesapeake Bay region may increase in the future, unless current management measures can adapt.

June 7, 15:40/S17-Oral-13142

### Dynamics of the *Vibrio* abundance related to changes in benthic composition at Polhena reef, Southern Sri Lanka

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Global climate change and anthropogenic stressors are connected to shift coral dominated reef systems in to macro algae dominated systems. However the mechanisms related to the shift of coral dominant reefs to algae dominated reef with climate and human stress not known. Recent evidences show that reef algal cover is positively correlated with microbial abundance where higher relative abundances of copiotrophic microbial taxa including proteobacterial such as *Vibrio*. *Vibrio* can be used as a culturable indication to assess coral reef health as a low tech tool. The present study was conducted to observe the activity of *Vibrio* to relate changes in benthic composition at Polhena reef located, Southern Sri Lanka during the thermal bleaching event 2016. Data were collected in two time periods separately November 2015 to January 2016 ( $T_1$ ) and December 2016 to February 2017 ( $T_2$ ). Photo quadrat method was used to assess benthic cover. *Vibrio* abundance was observed through selective agar plate count method by using Thiosulphate Citrate Bile salt Sucrose (TCBS) agar. In addition to that Coral Health Index (CHI) value was obtained via *Vibrio* score method to assess reef health. Results disclosed a huge decline of percentage live coral cover simultaneously with increase of percentage covers of algae from  $T_1$  to  $T_2$ . Also mean *Vibrio* abundance at  $T_2$  were significantly higher than that of in  $T_1$  ( $P= 0.012$ ;  $P< 0.05$  Paired T-Test; MINITAB 14). However, CHI indicated Polhena reef was microbiologically healthy where index value recorded in both time periods as 0.99 (CHI~1; 0= highly degraded, 1= healthy)

June 7, 16:20/S17-Oral-13185

### Advancing the practice of marine eco-compensation in China: Knowledge synthesis from implementation

Keliang **Chen**<sup>1</sup>, Stuart Pearson<sup>2,3</sup>, Xiao Hua Wang<sup>2,3</sup>, Hongxu Yu<sup>1</sup> and Julie Kesby<sup>2,3</sup>

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Marine eco-compensation practices have been carried out in the past five years as important measures to control sea use in many coastal zones of China. The historic development of the concept of marine eco-compensation provides a useful example of ecosystem-based thinking being adapted into practice in China. This comparative synthesis of the differences between these concepts and their implementation in the national context analyzes the theories and practices of current marine eco-compensation in China. This provides a synthesis of knowledge from implementing marine eco-compensation at three different scales (state level, provincial level, and city level) in China. The paper concludes that the establishment of marine eco-compensation based on marine ecosystem services valuation is very important in China because it provides; a way to avoid risks; a clear definition of methods and locally practical compensation standards; more stable funding sources; and feasible payment or allocation methods. Together these provide for ecosystem and environmental sustenance or improvement.

**Key words:** Marine eco-compensation; ecosystem services; marine protected areas

**June 7, 16:40/S17-Oral-13221**

**The Pacific Islands Vulnerability Assessment (PIVA): Initial findings from an expert panel workshop**

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The Pacific Islands Vulnerability Assessment, or PIVA for short, is one of a series of regional NMFS projects across the USA to quickly determine the impacts of climate change on a variety of fish and invertebrate taxa. The taxa for the PIVA exercise were chosen based on their importance to commercial and recreational fisheries, cultural harvests, as well as their importance to the ecosystem across geographies spanning the Hawaiian archipelago, Mariana archipelago, American Samoa, and the Pacific Remote Island Areas. A final list of 73 taxa was examined from coral reef, coastal non-reef, coastal pelagic, offshore pelagic, and deep-slope ecosystems from these regions. Species profiles were constructed using all available information relevant to the vulnerability of these taxa to climate change. An expert panel was recently conducted to summarize this information. Preliminary findings from this workshop will be presented.

**June 7, 17:00/S17-Oral-13110**

**Managing marine aquaculture health in a changing world**

Ryan **Carnegie**<sup>1</sup>, Simon R. M. Jones<sup>2</sup>, Lone Madsen<sup>3</sup>, Neil M. Ruane<sup>4</sup> and Marlene Areskog<sup>5</sup>

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As aquaculture production expands worldwide, managing the health of aquacultured populations, including preventing undesired disease interactions with wild animal populations, will increasingly be a challenge. Despite best efforts to maintain biosecurity, widening commerce alters distributions of pathogens and hosts, producing outbreaks of established diseases and the emergence of new ones. Anthropogenic impacts on the marine environment including ocean warming contribute to shifting host and pathogen distributions and introduce other possible influences on disease processes, from harmful algal blooms and ocean acidification to organic pollutants and microplastic contamination. In this evolving environmental landscape, the path to more effective management of animal health in marine aquaculture is not fully clear. Application of contemporary genetic methods for pathogen detection and discovery such as next-generation sequencing has garnered recent attention as part of the solution. Regardless of available diagnostics, however, disease occurrence remains a product of host and environmental factors in addition to those associated with the pathogen. Thus meeting the challenges of protecting aquaculture systems in a changing world will require incorporation of broader expertise into aquatic animal health, including chemistry and toxicology, physiology, genetics, oceanography, and ecology in addition to traditional areas of parasitology, microbiology and virology to better understand more complex and multi-factorial etiologies. Capacity to explore disease-associated factors in controlled experiments will remain essential. Fundamental to maintaining capacity for understanding disease in aquatic ecosystems will be societal commitment to broad-based science programs in support of the goal of aquaculture to support a growing human population in the 21<sup>st</sup> century.

## Workshops

### W1: Communicating and responding to climate change

**June 2, 9:10/W1-Invited-12882**

#### **Communicating complex climate change impacts to regional stakeholders: The cases of *Sargassum* influxes to the Caribbean Sea and community-collaboration adaptation**

Hazel Oxenford and Patrick McConney

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This talk will address the workshop objectives through giving examples of the challenges and successes in translating climate change science, specifically the current and potential impacts on the marine environment, into policy relevant and tangible actions for stakeholders in the Caribbean. The gap between science (facts and projections) and the public understanding is often wide and can lead to fear, misinformation, inaction, inappropriate action, or useful innovation. Here we use the recent spate of *Sargassum* influxes into the Caribbean as an illustration of early public perception and reaction, and of the challenges and rewards of conducting and communicating the science and lessons learned to a wide audience. In addition we touch on other Caribbean examples in which researchers are collaborating closely with coastal communities and mixed communities of interest to address climate adaptation often under conditions of limited capacity. These include information and communication technologies, vulnerability analyses and planning.

**June 2, 9:50/W1-Oral-12975**

#### **Communicating marine and coastal climate change impacts: Key findings and lessons learnt from the Pacific and Caribbean Regions**

Paul Buckley and Bryony Townhill

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The first 150 years of climate change science was characterised by occasional, but important reports and observations leading to a gradual development of knowledge over time. As research on climate change has proliferated in recent decades, including on marine impacts, the need for effective mechanisms to analyse and interpret this complex evidence base for policy makers, and wider society, has become more acute. In recent years, report cards have provided a valuable tool for the communication of climate change impacts to end users. Since their original inception in the UK over 10 years ago by the Marine Climate Change Impacts Partnership (MCCIP), there have been a wide range of similar publications, covering both marine and terrestrial impacts, and spanning a wide range of environments from tropical to polar regions. We report on key findings from two recent report cards from the Commonwealth Marine Economies Programme (CMEP) covering Caribbean, and more recently, Pacific, Small Island Developing States (SIDS). We also consider similarities and differences in the current state of scientific understanding across the two regions, key issues of concern, and the action being taken to address these concerns. The need for a clear understanding of different user needs, and the adoption of appropriate communication styles and channels to promote uptake in these regions is discussed. The experience we have gained in producing collaborative report cards in these regions are highly relevant to similar national and international initiatives being developed elsewhere.

**June 2, 10:10/W1-Oral-12916 CANCELLED**

**Analysis of United Nations voluntary commitments concerning marine protected areas and resilience**

Emily **Nocito** and Aaron Strong

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During the first week of June 2017, a high-level United Nations conference met at the UN Headquarters in New York City to discuss advancing implementation of Sustainable Development Goal (SDG) 14: to conserve and sustainably use the oceans, seas and marine resources for sustainable development. The primary modality for SDG 14 implementation target was through the creation of the voluntary commitment program. This “Call for Action” allowed relevant stakeholders – governments, non-governmental organizations, academic societies and intergovernmental organizations – from around the world to make a commitment in support of SDG 14. As of September 2017, 1,395 commitments were registered through the voluntary commitment process, spanning across organizations and disciplines and from all regions of the planet. These voluntary commitments are the mechanisms through which the international community hopes to advance conservation goals, such as the goal of increasing the percent of global ocean area under protection. Here, we present an analysis of the voluntary commitments that included proposals for Marine Protection Areas (MPAs) and discussed advancing “resilience”. Our analysis demonstrates the different ways in which ocean governance stakeholders treat the idea of resilience and the role of MPAs in increasing resilience. In doing so, we provide an empirical assessment of how rhetoric is deployed in a signature component of international ocean governance going forward, which will provide insights into the future of area-based management of the ocean.

**June 2, 11:00/W1-Oral-12757**

**Developing a Fish Manager’s Guide to climate change**

Lara J. **Hansen**<sup>1</sup>, Alex Score<sup>1</sup>, Roger Griffis<sup>2</sup> and Carolyn Lundquist<sup>3</sup>

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<sup>3</sup> National Institute of Water and Atmospheric Research, Hamilton, New Zealand

Climate change and ocean acidification impacts on fisheries will have significant effects on stocks and fishing activities. These impacts may have negative and positive consequences (e.g., changes in primary productivity or species range shifts disrupt an ecosystem in one area but allow for new fishing opportunities in another). Fisheries management must address both possibilities to decrease vulnerability and increase resilience often across jurisdictions. Managers are tasked with applying scientific and conservation principles to sustainably exploit fish stocks while minimizing negative effects on fish habitats, despite uncertainty. Climate change and ocean acidification will add an additional layer of complexity in balancing the extraction and conservation of fish stocks. Fisheries managers and scientists will need to plan and prepare for unavoidable effects of past, current and projected CO<sub>2</sub> emissions, as well as the compounding effects of non-climatic stressors. Traditional management tools, such as allowable catch, size restrictions, seasonal closures, gear restrictions, marine protected areas, habitat protection, and protection of spawning aggregations, may not be sufficient to sustain fisheries in the face of the combined effects of climatic and non-climatic stressors, which will affect fish stock populations, essential fish habitats, and the economies of fisheries-dependent communities. This talk will share progress on the development of a collaborative product, “The Fish Manager’s Guide to Climate Change,” modeled after the 2006 “Reef Manager’s Guide to Coral Bleaching,” including examples of management actions and tools being developed around the world.

**June 2, 11:20/W1-Oral-12760**

**A tale of two cities: How Sea Grant helped Tybee Island and St. Marys save money while saving lives**

Mona **Behl**

Athens, Georgia, USA. E-mail: mbehl@uga.edu

Low-lying communities in coastal Georgia are experiencing increased vulnerability to flooding events due to higher storm surges, heavy rainfall, antiquated stormwater infrastructure, and continued development within flood-prone areas. These events have resulted in the loss of property, health, safety, disruption of commerce and governmental services, and huge public expenditures and impairment of the tax base. The Cities of Tybee Island and St. Marys, recognized as major economic drivers of coastal tourism in Georgia, are particularly vulnerable to flooding. To address the impacts of coastal hazards, help communities in sustainable coastal development, and build a cohesive network of coastal leaders, Georgia Sea Grant collaborated with the Tybee Island to develop an award-winning Sea-Level Adaptation Plan. Extension professionals partnered with researchers to canvass a variety of stakeholders, generate cost-benefit analysis, model the impacts of king tides, and facilitate public information meetings. Participatory research, driven by stakeholder engagement, resulted in tangible savings. As a result of Sea Grant's efforts, Tybee Island achieved CRS (Community Rating System) rating of 5, enabling savings of \$725,639 annually in flood insurance premiums for property owners on the island. Inspired by the success of Tybee Island Sea-Level Rise Initiative, St. Marys collaborated with Georgia Sea Grant to implement a new Flood Damage Prevention Ordinance, and entered the CRS at a level of 7, resulting in citywide savings of \$87,740 annually in flood insurance premiums. To date, Georgia Sea Grant has helped 16 coastal counties and cities in Georgia to become active participants in the CRS.

**June 2, 11:40/W1-Oral-12850**

**Adapting to climate change: The UK Climate Change Risk Assessment (CCRA), National Adaptation Programme (NAP) and Adaptation Reporting Powers (ARP) – An integrated approach**

John **Pinnegar**<sup>1,2</sup> and Paul Buckley<sup>1</sup>

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<sup>2</sup> School of Environmental Sciences, University of East Anglia (UEA), Norwich, UK

The United Kingdom Climate Change Act (2008) introduced a requirement for the Government to assess the risks and opportunities presented by climate change and to prepare for the challenges ahead in an integrative and coordinated way. Specifically this legislation mandated the need for: (1) a UK-wide Climate Change Risk Assessment that must take place every five years to quantify the level of threat; (2) a National Adaptation Programme which must be put in place every five years to address the most pressing climate change risks in England, and (3) powers to direct companies with functions of a public nature, to prepare reports on how they themselves are assessing and acting on risks and opportunities from a changing climate. This contribution will focus on 'lessons learnt' from the 1st and 2nd round of the CCRA and NAP process in 2013 and 2017. It will focus on the characterisation and quantification of maritime risks specifically, and how outputs were taken-up and used by stakeholders or policy makers. So far, more than 100 UK companies and public authorities have published reports on climate-change adaptation (under the 'Adaptation Reporting Power' (ARP), including most energy and water suppliers as well as several with responsibility in the maritime environment (i.e. port operators, Marine and Coastguard Agency, the sea fisheries industry authority, Marine Management Organization. Whether or not this has enhanced long-term resilience in the UK will be discussed.

**June 2, 12:00/W1-Oral-12976**

**10,000 voices on marine climate change in Europe: What does the public know...and really care about?**

Paul **Buckley** and John Pinnegar

Cefas, Pakefield Road, Lowestoft, Suffolk, UK. E-mail: paul.buckley@cefas.co.uk

Over the past few decades, substantial funding has been directed toward improving scientific understanding and management of climate change impacts in the marine environment. However, little is known about how much of this information is reaching the public. Whilst there is a growing body of literature on public perception of climate change impacts more generally, little has been done on the public understanding of marine climate change impacts in particular. We report on findings from a pan-european study of over 10,000 citizens that was specifically focussed on public perception of marine climate change issues in 10 countries. We place the findings in the context of wider public concern about marine environmental topics (e.g. over-fishing; pollution). Across Europe, how informed and concerned the public were varied markedly (by country, gender and age), as did the trust they placed in different types of media and organisations (including scientific institutes) that they received climate change information from. In terms of policy actions, most respondents highlighted mitigation measures as opposed to local-scale adaptation. Younger participants prioritized actions associated with reducing carbon emissions, whereas older age groups prioritized more immediately visible actions, such as improving coastal defenses. Findings from this study are compared with other national and international studies of public perception to identify consistent messages and common insights. Successful adaptation to the impacts of climate change requires public engagement and support for policy decisions, and the use of innovative approaches to take account of differences among demographic groups and nationalities demonstrated in this study.

## **W2: Advances in Earth System Models (ESMs) for marine applications**

**June 2, 13:30/W2-Invited-13171**

### **Earth System Models and marine ecosystems in the context of climate variability and change**

Matthew **Long**

National Center for Atmospheric Research, Climate and Global Dynamics Laboratory, Boulder, Colorado, USA. E-mail: mclong@ucar.edu

Earth system models (ESMs) aim to provide a comprehensive basis for simulating the climate system, including the role of ecological processes in mediating the carbon cycle. A common application of these models is to develop centennial-scale climate projections under scenarios describing human activities. Fully-coupled climate dynamics and a mechanistic carbon cycle enable ESMs use specified external forcing (i.e., CO<sub>2</sub> emissions) and prognostically solve for carbon-climate feedbacks affecting natural sinks. Earth system modeling is a highly ambitious enterprise and the models fall short of our aspirations in many respects; ESMs remain, however, a powerful tool for simulating and understanding interactions between climate and marine ecosystems. In this talk, I will provide an overview of state of the art Earth system modeling frameworks, including recent and planned developments to ocean ecosystem components. I will also present some example studies applying ESMs to problems relevant to marine ecology in context of climate variability and change.

**June 2, 14:30/W2-Oral-12960**

### **Development of the marine ecosystem model OECO2 to be embedded into the Earth system model MIROC-ES2**

Michio **Watanabe**<sup>1</sup>, Maki Noguchi-Aita<sup>2</sup> and Tomohiro Hajima<sup>3</sup>

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The emission of a large amount of anthropogenic carbon dioxide (CO<sub>2</sub>) changes the global carbon cycle, contributing to temperature increase as well as ocean acidification. In addition, the global nitrogen cycle, which is perturbed by industrial fixation, is thought to affect the global carbon cycle. To project future global climate and biogeochemical changes, the Earth system model MIROC-ES2 including the global carbon and nitrogen cycles is under development. To embed into the new ESM, we developed the new marine ecosystem model OECO2 that includes riverine and atmospheric nitrogen inputs as well as iron, oxygen, and phosphate cycles. Note that, in this model, denitrification and nitrogen fixation are taken into account. Dissolved iron is supplied from the mineral dust and sediments. Our model shows that the primary production is limited by low iron concentration in High-Nutrient, Low chlorophyll (HNLC) regions and nitrification occurs in low latitudes. It also displays that denitrification occurs under low-oxygen conditions in the subsurface waters. We briefly introduce this marine ecosystem model and its preliminary results.



**June 2, 14:50/W2-Oral-13077**

### **Ocean Ecosystem Dynamics in GFDL's CMIP6 Earth System Model GFDL-ESM4**

Charles **Stock**<sup>1</sup>, John P. Dunne<sup>1</sup>, Jasmin John<sup>1</sup>, Niki Zadeh<sup>1</sup>, John P. Krasting<sup>1</sup>, Charlotte Laufkötter<sup>2</sup>, Alistair Adcroft<sup>1,3</sup>, Paul Ginoux<sup>1</sup>, Elena Shevliakova<sup>1</sup>, Sergey Malyshev<sup>1</sup>, Fabien Paulot<sup>1,3</sup> and Larry Horowitz<sup>1</sup>

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<sup>3</sup> Princeton University, Program in Atmospheric and Oceanic Sciences, Princeton, NJ USA

NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) has developed a new Earth System Model, ESM4, for CMIP6 and in support of IPCC AR6. This model includes several advances for ocean ecosystem applications relative to GFDL's previous ESM2 series. The resolution has been doubled relative to ESM2, to 1° and 1/2° in the ocean and atmosphere, respectively. The atmospheric simulation relies on GFDL's new AM4 atmospheric model that significantly reduces surface radiation biases that propagate to marine systems. The ocean simulation relies on GFDL's 6th generation Modular Ocean Model (MOM6) that features improved numerics, flexible vertical coordinates, and refined ocean mixing dynamics relative to MOM5. Ocean biogeochemistry is simulated with the Carbon, Ocean Biogeochemistry and Lower Trophics (COBALT) model that has enhanced resolution of plankton food webs and the energy flow between phytoplankton and fish. ESM4 also features more dynamic coupling of nutrients (iron, nitrogen) between the land, atmosphere, and ocean systems. ESM4's marine ecosystem climatology and response to variability will be compared against observations, ESM2 and other AR5 models to critically assess improvements and persistent challenges. The comparison will focus on prominent potential marine ecosystem stressors, including temperature, oxygen, pH, primary production, and the energy flow from phytoplankton to fish.

**June 2, 15:10/W2-Oral-13061**

### **Multiyear climate prediction by using 4D-Var coupled data assimilation system**

Takashi **Mochizuki**, Shuhei Masuda and Yoichi Ishikawa

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An initialization relevant to interannual-to-decadal climate prediction has usually used a simple restoring approach for oceanic variables. Here, we demonstrate the potential use of four-dimensional variational (4D-Var) data assimilation on the leading edge of initialization approach particularly in multi-year (5-year-long) climate prediction. We perform full-field initialization rather than anomaly initialization and assimilate the atmosphere states together with the ocean states to an atmosphere-ocean coupled climate model. In particular, it is noteworthy that ensembles of multi-year hindcasts using our assimilation results as initial conditions exhibit an improved skill in hindcasting the multi-year changes of the upper ocean-heat-content (OHC) over the central North Pacific. The 4D-Var approach enables us to directly assimilate a time trajectory of slow changes of the Aleutian Low that are compatible with the sea-surface-height and the OHC. Consequently, we can estimate a coupled climate state suitable for hindcasting dynamical changes over the extratropical North Pacific as observed. In addition, we will also illustrate applicability of our system to El Niño predictions, by both raising a level of model performance and improving quality of initial conditions.

**June 2, 16:00/W2-Oral-12754**

### **Impact of eddy mixing on the sensitivity of ocean biogeochemical cycling to doubled CO<sub>2</sub> within an earth system model**

Alexis **Bahl** and Anand Gnanadesikan

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The lateral mixing coefficient in the ocean is poorly constrained by observations, with values ranging over several orders of magnitude. Although a consensus picture of mixing is starting to emerge from recent observational and theoretical work, this picture has not been incorporated into the Earth System Models used for projecting climate change, and values of the mixing coefficient used in models vary between a few hundred and a few thousand m<sup>2</sup>/s. In previous work, we developed a series of Earth System Models varying only in the value of the mixing coefficient, with constant values ranging from 400 to 2400 m<sup>2</sup>/s and a spatially varying pattern based on altimetric measurements that is closer to the current consensus. We showed that the choice of coefficients has important implications for the simulation of low-oxygen waters and the uptake of anthropogenic carbon dioxide. In this talk we examine the importance of the mixing coefficient,  $A_{\text{edi}}$ , for the sensitivity of biogeochemical cycling to an instantaneous doubling of carbon dioxide, focussing on the changes in oxygen and in export production. The model used in this project, ESM2mc and ocean module, BLING, highlights the sensitivity associated with constraining the parameterized diffusion coefficient. Lastly, there are large differences found in convection and therefore the volume of oxygen minimum zones between different values. This uncertainty greatly impacts the way hypoxic zones are displayed within an Earth System Model, as well as the analysis to increased CO<sub>2</sub> under anthropogenic climate change.

**June 2, 16:20/W2-Oral-12789**

### **Response of O<sub>2</sub> and pH to ENSO in the California Current System in a high resolution global climate model**

Giuliana Turi<sup>1</sup>, Michael Alexander<sup>2</sup>, Nicole **Lovenduski**<sup>3</sup>, Antonietta Capotondi<sup>2,4</sup>, James Scott<sup>2,4</sup>, Charles Stock<sup>5</sup>, John P. Dunne<sup>5</sup>, Jasmin John<sup>5</sup> and Michael Jacox<sup>6</sup>

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We used a high-resolution global climate model (with a ~10 km ocean grid) to investigate the influence of El Niño/Southern Oscillation (ENSO) events on the physics and biogeochemistry of the California Current System (CalCS). We focus on the effect of ENSO on variations in the O<sub>2</sub> concentration and the pH of the coastal waters of the CalCS. An assessment of the CalCS response to six El Niño and seven La Niña events reveals significant variations in the response between events. However, these variations overlay a consistent physical and biogeochemical (O<sub>2</sub> and pH) response in the composite mean. The mean response indicated that O<sub>2</sub> and pH are affected rather differently in the euphotic zone above 100 m. The strongest O<sub>2</sub> response reaches up to several 100 km offshore, whereas the pH signal occurs only within a 100 km -wide band along the coast. By splitting the changes in O<sub>2</sub> and pH into individual physical and biogeochemical components that are affected by ENSO variability, we found that O<sub>2</sub> variability in the surface ocean is primarily driven by changes in surface temperature that affect the O<sub>2</sub> solubility. In contrast, surface pH changes are predominantly driven by changes in dissolved inorganic carbon (DIC), which in turn is affected by upwelling, explaining the confined nature of the pH signal close to the coast. Anomalously low O<sub>2</sub>, pH, and aragonite saturation occurred during La Niña below 100 m, indicating that the CalCS ecosystem could periodically undergo stress in addition to impacts due to climate change.

## **W3: Exploring potential ocean-based solutions to climate change impacts on marine biodiversity and ecosystem services**

**June 3, 9:30/W3-invited-13254**

### **Aquaculture in a Changing Climate: Lessons from China**

Ling **Cao**

Center on Food Security and the Environment, Stanford University. E-mail: caoling@stanford.edu

Aquaculture plays a key role in enhancing the global food security by providing food, essential nutrients and livelihoods to billions of people. The long-term sustainability of this sector is challenged by overfishing, pollution, habitat degradation, and climate change. There is a growing concern regarding the threats of ocean acidification and sea level rise caused by climate variation on marine aquaculture. To help mitigate and reduce impacts from climate change and sustain the future development of marine aquaculture, identifying flexible and appropriate adaptation strategies and risk reduction initiatives would be key. Given China is the largest aquaculture producer in the world and contributes approximately two-thirds of the global aquaculture production, this talk will use Chinese marine aquaculture as an example to discuss the adaptation strategies currently adopted and priorities for future research on climate change adaptation for aquaculture and its dependent communities.

**June 3, 11:00/W3-Oral-12373**

### **Impacts of Climate Change on Mangrove Biodiversity and Sustainable Livelihoods along Lagos Coast of West Africa**

Abdulwakil O. **Saba**<sup>1</sup>, Rafiu O. Kolade<sup>1</sup> and Isa Olalekan Elegbede<sup>2</sup>

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Mangroves offer numerous ecosystem services, however, momentous consequences result when they get depleted. This study, therefore, investigates the impacts of climate change on mangrove biodiversity along the Lagos coast with particular reference to sustainable livelihoods for effective adaptation and mitigation efforts. Primary data was collected from flora and fauna sampling, field survey, questionnaires, interviews and review of the literature. Simpson's (D), Simpson's diversity, Simpson's reciprocal, Shanon Weiner's (H), Equitability, Evenness (E) and Margalef's indices ranged from 0.269-0.368, 0.632-0.731, 2.717-3.717, 1.003-1.460, 0.095- 0.948, 0.822-0.948, 0.677-1.125, respectively, with corresponding means of  $0.324\pm 0.045$ ,  $0.669\pm 0.044$ ,  $3.124\pm 0.423$ ,  $1.167\pm 0.206$ ,  $0.693\pm 0.4$ ,  $0.673\pm 0.440$ ,  $0.817\pm 0.212$ . Although urbanization, deforestation and agricultural activities have contributed greatly to the loss, climate change is progressively aggravating it due to impacts such as temperature increase, sea level rise acidification and changes in wind patterns. Therefore, coupled with efforts aimed at mitigating other stressors, climate change adaptation and mitigation measures need to be implemented in order to guarantee the sustainability, not only of the mangrove flora and fauna but also of the livelihoods of adjacent communities who benefit largely from these resources and are also vulnerable to the consequences of its depletion.

**Keywords:** Mangroves, livelihoods, fisheries, coastal communities, Lagos coast

**June 3, 11:15/W3-Oral-12710**

## **Using resilience assessment to understand the dynamics of marine socio-ecological systems in order to inform climate-change-smart marine spatial planning processes**

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The concept of resilience has gained widespread popularity over the past few decades. As Climate Change (CC) advances, there is an increasing need to develop tools that can provide guidance on how to enhance management and governance of the marine spaces. Invariably, coastal and marine management issues are not just ecological or social issues, but have multiple integrated elements which require the need to make resilience thinking central. Marine/Maritime Spatial Planning (MSP) is becoming apparently and increasingly used as a veritable forward looking tool for managing coastal and marine uses, resources and activities for stable/maximum long and short-term social-economical and environmental gains. However In the face of accelerated CC, today's marine spatial plans need to take into cognisance socio-ecological systems, in which cultural, political, social, economic, ecological, technological, and other components interact in the marine and coastal domain. This paper therefore takes a theoretical research approach, using the resilience assessment framework provided by the Resilience Alliance for a case-study review of selected marine spatial plans in Europe, America and Asia to assess if the dynamics of change in social-ecological systems for climate change were taken into consideration in their planning processes. These assessments revealed that most of the plans only assume insights from complex adaptive systems and does not consider general system-wide CC resilience in their actions taken to address issues. This paper therefore concluded by proposing a methodology to integrate key concepts of resilience to provide an alternative way of thinking about CC in MSP processes.

**June 3, 11:30/W3-Oral-12830**

## **Designing climate-smart ocean plans**

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Multi-sector ocean planning is increasingly used as a tool to mitigate conflicts over space in the sea, but key questions include whether and to what extent static ocean plans are robust to dynamic climate change. Here, we use more than 20,000 projections for 658 marine animals around the North American coast to show that one third of species may be replaced within existing Marine Protected Areas (MPAs) by the end of the century. However, we also identify practical solutions. Networks of protected areas were exposed to half as much turnover, and preparing for species redistribution, even within static multi-sector ocean planning, produced meaningful reductions in climate exposure without requiring substantial tradeoffs for other ocean users. While climate change will severely disrupt many human activities, we find a strong benefit to proactively planning for long-term ocean change, even in the face of substantial uncertainty.

**June 3, 11:45/W3-Oral-13168**

**Eliciting and evaluating climate adaptation strategies for fisheries and fishing communities**

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Across the globe, climate change is affecting marine ecosystems, fish populations, and fisheries. At local scales, climate impacts emerge in distinct ways depending on the nature and rate of ecosystem change, ways in which societies use marine resources, and adaptive capacity. In the Northeast United States, marine waters have warmed rapidly over the past decade, and impacts have been felt in culturally and economically important fisheries. Fisheries are responding to changes in resource populations and the marine ecosystem in a variety of ways: fishermen travel further to target their traditional species, switch to new species that have become prevalent in their typical fishing areas, and diversify into opportunities outside of capture fisheries. However, adaptation has largely been limited to individual-level and industry-motivated actions to date, and there is an expectation that institutional-scale change will become necessary to facilitate sufficient adaptation. Interviews with fishery stakeholders and municipal officials in four Northeast U. S. ports (i.e., Stonington, ME; Portland, ME; New Bedford, MA; Point Judith, RI) that span a range of geographies and fisheries reveal ways in which fishermen and their communities have already responded to climate-related ecosystem changes, ways in which they want to be able to adapt in the future, and factors that facilitate and constrain adaptation. These interviews also reveal how climate change is situated against broader social, cultural, and economic concerns as well as strategies that will broadly promote resilience in fishing communities.

## **W4: Climate change adaptation of fisheries and aquaculture: Examples of field projects supporting countries and communities**

**June 3, 13:35/W4-Invited-13261**

### **Building capacity to adapt to climate change in communities engaged in small-scale fishing and aquaculture**

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Vulnerability analysis typically combines indicators of exposure to climate-related hazards, and indicators of sensitivity to those hazards, with a measure of system 'adaptive capacity'. It is proposed that such capacity can be deployed to reduce potential impacts of climate change on the system being considered. Measures of adaptive capacity are often rather generic. It is assumed that greater adaptive capacity is found in: wealthier countries, regions, communities or households; in political constituencies that are well-governed by functional institutions; in geographies with diverse and growing economic bases; or in well-informed and well-educated populaces. These analyses can be useful to identify vulnerable economic sectors, geographies or social groups, but they are seldom useful to inform what to do once such vulnerabilities are identified. If you are vulnerable because you live in a country with low GDP and weak governance, you can build adaptive capacity by raising GDP, building stronger institutions, or moving to a country with higher GDP and better governance. This is not especially helpful or insightful advice. How, then, can we consider dimensions of adaptive capacity that can be built, in practice? A recent framework identifies five domains of adaptive capacity: the assets that people can upon in times of need; the flexibility to change strategies; the ability to organize and act collectively; learning to recognize and respond to change; and the agency to determine whether to change or not. In this paper, I propose using this framework to assess adaptive capacity at sub-national and local levels, and using the assessment as a means to identify priority action to build adaptive capacity. I propose that the work presented in this session could be aligned with this framework to provide a series of comparative case-studies in climate adaptation in fishery and aquaculture-dependent communities. Such a bank of case studies could be used to identify the most promising ways to build adaptive capacity.

**June 3, 14:40/W4-Oral-13060**

### **The role of ocean planning in adapting to global climate change impacts**

Catarina Frazão-Santos<sup>1</sup>, Tundi Agardy<sup>2</sup>, Francisco Andrade<sup>1</sup>, Manuel Barange<sup>3</sup>, Larry B. Crowder<sup>4</sup>, Charles N. Ehler<sup>5,6</sup>, Michael K. Orbach<sup>7</sup> and Rui Rosa<sup>1</sup>

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Planning of marine areas from coastal to open-ocean regions is taking place worldwide as a way to foster sustainable ocean management and governance. This planning process, most often termed marine spatial planning (MSP), organizes the distribution of ocean uses in space and time, as well as the interactions among human uses and between uses and the marine environment. MSP can, therefore, be an operational approach to "manage the inevitable" (i.e. a changing ocean), and to adapt to climate change effects. Human uses that rely on marine ecosystem goods and services, such as fisheries, aquaculture, or tourism, are expected to undergo spatial and temporal change as climate change alters ocean conditions and, subsequently, the distribution of ocean ecosystem services. Indeed, as ocean uses decrease or increase, or are relocated, new use-use and use-environment conflicts are expected to arise (e.g. issues with legal permits, cumulative environmental impacts). MSP can plan for these changes, and thus mitigate some negative climate-related impacts. Planning for a changing ocean will allow for better preparedness, improved response capacity and, ultimately, a reduced vulnerability of marine socio-ecological systems. This, however, implies flexible and adaptive MSP. Here we will examine and discuss the role of MSP in adapting to global climate change impacts, particularly by addressing the challenges involved in it.

June 3, 15:00/W4-Oral-13059

## Addressing climate change-driven uncertainties in maritime spatial planning through Cumulative Effects Assessment

Elena **Gissi**<sup>1</sup>, Elisabetta Manea<sup>1</sup>, Stefano Menegon<sup>2</sup>, Giulio Farella<sup>2</sup>, Daniel Depellegrin<sup>2</sup>, Davide Di Carlo<sup>1</sup>, Chiara Venier<sup>1</sup>, Alessandro Sarretta<sup>2</sup>, Andrea Barbanti<sup>2</sup> and Francesco Musco<sup>1</sup>

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Maritime spatial planning (MSP) consists in a decision-making process aiming at allocating uses at sea while controlling multiple stressors on marine and coastal ecosystems. Climate change (CC) is predicted to drive significant changes in the marine and coastal environments. Understanding the response of ecosystems to CC effects is high in research agendas. Less attention is paid to how MSP, as a decision making process, will incorporate uncertainty derived by climate change to provide insights for the application of the precautionary principle. In MSP, Cumulative Effects Assessment (CEA) is usually considered as a model to inform decision making because it spatially identifies impacted areas at various level. In this study, we consider CEA as a tool to identify areas where the uncertainty from CC will plausibly be higher, because of the CC projections and related uncertainties. Drawing from the current state of the art on the CEA, we identify gaps and limitations in CEA considering climate change-driven sources of uncertainties. A general uncertainty framework is applied in order to depict sources of uncertainties deriving from projections and potentially driven changes from CC effects. The analysis is proposed for the CEA framework of the Adriatic and Ionian Region (AIR) in the Mediterranean Sea, where severe changes are expected on ecosystems and their capacity to provide goods and services. Results are discussed with respect to the science-policy nexus, as well as with respect to policy agendas in the AIR, in order to support decision making with knowledge that is consistent to the MSP scoping.

## **W5: Climate Change and Fishing Communities: Interactions with Environmental Conservation, Sustainable Livelihoods and Food Security**

**June 3, 9:15/W5-Oral-13259**

### **A Community Focus: How local communities are dealing with climate change and environmental threats to build sustainable livelihoods and food security**

Anthony **Charles**

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Local communities, and coastal communities in particular, have a very extensive and largely undocumented record of conservation practices that counter local environmental threats and sustain local resources. Often motivating these efforts, and benefiting from them, is the imperative of sustaining local livelihoods and food security. The difficulties faced in achieving this trio of goals – conservation, livelihoods and food security – is being exacerbated by climate change. In particular, coastal communities are facing increased vulnerability to shocks and stresses, if their adaptive capacities and ecosystem services are further eroded, with risks to lives and livelihoods, income, food security, poverty reduction and economic performance. This presentation focuses on coastal communities to explore the 3-way interaction of climate change, local environmental stewardship and human needs, notably livelihoods, food security and poverty alleviation. Building on related considerations in the Small-Scale Fisheries Guidelines, the presentation aims to highlight pathways toward more effective climate adaptation, greater resilience of coastal communities, and better policy to overcome what can be major obstacles to human and social development in coastal areas of the world.

**June 3, 9:45/W5-Invited-13239**

### **Creating an enabling environment to support disaster risk reduction in the context of the Small-Scale Fisheries Guidelines. Lessons from Bangladesh**

Mohammad Mahmudul **Islam**

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The Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (the SSF Guidelines), which was endorsed by FAO member states in 2014, is the first internationally agreed instrument dedicated wholly to the small-scale fisheries of the world. This instrument included some guidelines to address disaster risk and climate change impacts, as they affect the food-security, livelihoods and personal safety of the small-scale fishers. Situated in a low-lying delta, Bangladesh is extremely vulnerable to a range of climate-related extreme events like cyclones, to slow onset processes like sea level rise that incurred loss and damage to resources. Nevertheless, over the past four decades, Bangladesh has been able to significantly reduce disaster-related mortality, by adopting different good practices in disaster risk management. This success created the premise for implementation of SSF Guidelines. Bangladesh has created several enabling conditions including a robust policy and legal framework, the presence of a strong network of NGOs, functional social safety program for priority consideration of vulnerable population and food security, disaster management organizations at all level of local government. Bangladesh also invested in building physical infrastructures and local economy development for long-term resilience focusing on the concept of “building back better”. These strategies are particularly aligned with the SSF Guidelines related to disaster risks and climate change impacts. Still, to ‘walk the talk’ of the full implementation SSF Guidelines, it is essential to foster institutional coordination and collaboration through the active participation of small-scale fishers in the decision-making process. In this process, political will, empowerment of small-scale fishers, awareness building and capacity building is necessary. The learning from the Bangladesh experience can be replicated and implemented in other regions facing similar challenges in the context of disaster risk reduction.



**June 3, 10:00/W5-Invited-13241**

## **Communities, Climate Change and Adaptation Strategies - Variability and Viability**

Jake Rice

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The idea of ‘fishery-dependent communities’ is a commonly encountered term that highlights the importance of fishing to many coastal communities worldwide. However, the focus on fisheries invites one dimensional approaches to the complex challenges of coastal community viability in a changing world. This talk will explore some of the complexities that must be addressed if our research is to be relevant to coastal communities and small-scale fisheries, and opportunities that can contribute jointly to more viable communities and better conservation and sustainable use of coastal resources.

The question of what coastal communities need to know about climate change, for the fish stocks they harvest, is not simple. To prepare adaptation strategies, communities need to know what resources will be present in the local coastal areas and bays, recognizing that human communities take their livelihoods from the full biotic community. Independent predictions of future ranges and abundances of the dominant commercial species are valuable but incomplete. Community fisheries cannot plan successful adaptation strategies without broader information on fish community properties, such as aggregate productivity and size spectra, seasonality and timings of fishing opportunities. They need this information to adapt their integrated lifestyles - shifting focus among their gears and their places to fish, as well as blending fishing with tourism and other uses of the sea. These types of forecasts of biotic community properties and timing of seasonal oceanographic events will be difficult to produce and require adjustments to the scope and focus of the climate model scenario outputs.

The forecasts are crucial, though, because evidence is accumulating that communities can be very effective stewards of their local marine resources and ecosystems. However, they need to have the information and empowerment to plan and act collectively for conservation as well as sustainable use of those resources. The “information” means not just having models that make the necessary forecasts, but also integrating the outputs with the many-generational knowledge of those coastal communities, so they have a context to use the forecasts.

“Empowerment” may be even more complex. Communities need the local flexibility to match their adaptation strategies to community goals and culture. Furthermore, a patchwork of independent community strategies will be inefficient to develop, and more importantly ineffective to implement, unless neighboring communities have inter-compatible strategies. The governance approaches needed for this blend of flexibility and coordination have not yet been identified and tested.

**June 3, 11:00/W5-Oral-12347**

## **Indigenous fishers in the Philippines: Adaptation to Climate Change**

Maria Rebecca Campos

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Climate change has aggravated the marginalized condition of indigenous fishers in the Philippines. It is worth noting, however that the relationship of many indigenous peoples to their natural environment such as the land, the sea, plants and animals incorporates them as part of the same environment. The cultural and religious belief systems of indigenous peoples influence their interaction with the natural environment to shape their environmental adaptation. There are cases of seasonal immigration of fishers like the “Tumondoks” who visit other islands where the fishing grounds are rich. They coexist harmoniously with the “Pangayaws”, another indigenous group, without any issue on territorial rights. The “Maguindanaons” chant prayers while on their way to fish and sightings of floating dead snails or shells in the waters is a sign that should not proceed to fish. Climate change has however, proven that their traditional fishing methods and practices are not enough. The “Badjaos” have a unique coastal based resource management of their own. Through a UNDP study tour, they realized that artificial reefs and marine protected areas have been successful with other indigenous peoples like the “Tinigbas”. Success stories like these when imparted to their fellow indigenous fishers are easier to adapt. Likewise the same was done in the case of “Badjao” seaweed farmers in Tawi-tawi who provided best case practices to the seaweed growers in Surigao. The strategy framework to climate change for local resilience is proposed and recommended to all institutions and indigenous communities concerned for environmental adaptation to climate change.

**June 3, 11:15/W5-Oral-12467**

## **Assessment of Yawri Bay Marine Protected Area Vulnerability to Climate Change in Sierra Leone**

Sheku Sei<sup>1,2</sup> and Andrew Baio<sup>2,3</sup>

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Overcapitalization from the open access fisheries regime and illegal destructive fishing in sensitive coastal communities, warranted the institution of territorial use rights in fisheries (TURF) through co-managed marine protected areas (MPA) in Sierra Leone. The Yawri Bay MPA located in Southern Sierra Leone has been performing progressively well, where community management associations (CMAs) are controlling illegal fishing in their localities. However, the effects of climate change on fishing communities located in and around the Yawri Bay in Southern Sierra Leone have impacted on the livelihoods of fishers. Coastal Erosions have inundated homes of fisherfolks who have been forced to quickly relocate to safer zones at heavy costs. These communities are heavily reliant on fisheries for income, food and employment, but they have low capacity to respond to adverse climatic impacts to protect livelihood elements and tenure rights. This research tries to evaluate the cause and impacts of climatic variation on these fishing communities through vulnerability assessment of climate change impacts. The MPA establishment process has been described and a multi-criteria decision making appraisal of vulnerability of Yawri Bay to climate change revealed challenges for the sustainability of MPA management initiatives including alternative livelihood supports. These challenges have been detailed as lessons learnt and safeguards that could be useful to other coastal artisanal fisheries elsewhere, that are under the influence of climate change and desirous of instituting right based fisheries management. It is strongly recommended that the development of climate change adaptation strategy should be incorporated into community bye-laws implemented by the CMAs involved in MPA management and territorial use rights fisheries in Sierra Leone.

**Keywords:** Sierra Leone, Climate change, Yawri Bay marine protected area, Territorial Use rights in fisheries, livelihoods

**June 3, 11:30/W5-Oral-12599**

## **Factors influencing the climate change adaptation efforts: Discussions from the case of coastal Tamil Nadu, India**

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The 2004 Indian Ocean Tsunami made extensive damages in the coastal areas of southeastern coastal Tamil Nadu, India. A good deal of research has shown how the 2004 Indian Ocean tsunami effects have made long term damages to the coastal systems and how it has triggered the changes in weather and climate patterns. For the past one decade, socioeconomic lives of coastal fishing communities in Tamil Nadu have considerably improved due to the rehabilitation measures of both governmental and non-governmental organizations. However local researches show that small-scale fishermen are highly vulnerable to the integrated effects of indirect effects of tsunami (2004) disaster and climate change. We know far less about how such social, cultural and economic changes intersect among each other and influence the perceptions and institutional adaptation activities of coastal fisherfolk to adapt such integrated impacts. In such context, this paper sets to understand the socioeconomic changes and the resultant institutional changes for the past one decade in the research setting. Then it explores how such changes influences the perceptions and institutional adaptation efforts of small-scale fisherfolk to adapt to climate change. Drawing from qualitative empirical evidences in selected tsunami (2004) affected fishing hamlets in coastal Tamil Nadu, India, this paper argues that the perceptions and adaptation activities to the integrated effects of climate change and its concomitant outcomes and long-term impacts of tsunami (2004) strongly vary on socioeconomic differences, social and institutional capital of the coastal fisherfolk.

**June 3, 11:45/W5-Oral-13245**

**Social vulnerability to climate change of fishing communities across the South Brazil Bight**

Ivan Machado Martins and Maria A. **Gasalla**

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Small-scale fishing communities are often susceptible to climate change impacts especially due to the scale of their activities and limited spatial mobility at sea. Demographic and policy trends may also limit their adaptive capacity to cope with changes. To identify the vulnerability and adaptation patterns to climate change among different coastal communities across a large marine ecosystem, a comprehensive multi-scale vulnerability framework developed by an international project was adopted. A total of 151 fishers were surveyed at the household level in eight carefully selected coastal fishing communities that represent the broad characteristics of regional livelihoods. Measurable indicators were used to assess the sensitivity, exposure, adaptive capacity, and vulnerability scores of each community. Our findings show that remoteness and lack of climate change-related institutional support increase vulnerability, while community organization, occurrence of strong leadership, partnership with research activities, community-based co-management and livelihood diversification reduce vulnerability. Overall, the key drivers that increase or decrease the vulnerability of fishing communities to climate change are components of adaptive capacity. Among the communities, Pontal de Leste, Ilha do Araújo and Boqueirão Sul showed the highest vulnerability to climate change, while Enseada, Mandira and Itaipu showed the lowest vulnerability. This assessment is the first one to focus on social vulnerability to climate change in regional fishing communities and provides a better understanding of climate change effects in coastal zones, local factors driving vulnerability and perspectives on more resilient and adaptable systems.

## **W6: Utilizing bioenergetics measurements and modeling to evaluate climate change effects on marine species and ecosystems**

**June 2, 9:10/W6-Invited-13078**

### **Predicting marine ecosystem population and food web responses to environmental variation: Now is the time to merge bioenergetics and movement ecology**

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Bioenergetics has been the focus of sustained investigation for decades, both with advances in data collection and modeling. Dynamic energy budget modeling is widely used and there is a new release of the Wisconsin bioenergetics software package for fish. Bioenergetics of the individual is increasingly being combined with mortality and reproduction to enable population and food web modeling. Recently, there has been an explosion of interest in collecting data and modeling of how organisms move through dynamic multi-factor environmental fields. This includes fine-scale movements (e.g., escaping predators) and larger-scale (e.g., spawning migration). The collection of individual movements lead to higher-order emergent properties such as population biomass and distributional changes, as well as food web-level responses. As with bioenergetics, there have been advances in data collection (e.g., tracking data) and modeling of behavioral movement. It is time to couple and integrate these two approaches into a single system where growth, mortality, and reproduction are explicitly two-way linked to movement decision-making and resultant movement behaviors. Until now, most work has emphasized growth, mortality, and reproduction or movement. The data becoming available and the advances in modeling provide a window of opportunity for integrating these two approaches so that energetics dynamically affects movement and movement dynamically affects energetics. I will attempt to present a unifying framework that encompasses the processes of growth, mortality, reproduction, and movement, and use examples to illustrate the benefits of an integrated approach and some key issues for predictions at the population and food web levels.

**June 2, 9:45/W6-Oral-12973**

### **Issues on elucidation of climate variability impacts on living marine resources and future perspectives**

Shin-ichi **Ito**<sup>1</sup>, Tetsuichiro Funamoto<sup>2</sup>, Osamu Shida<sup>3</sup>, Yasuhiro Kamimura<sup>4</sup>, Motomitsu Takahashi<sup>5</sup>, Kotaro Shirai<sup>1</sup>, Tomihiko Higuchi<sup>1</sup>, Kosei Komatsu<sup>1</sup>, Takaaki Yokoi<sup>1</sup>, Tatsuya Sakamoto<sup>1</sup>, Chenying Guo<sup>1</sup> and Toyoho Ishimura<sup>6</sup>

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Various studies have been conducted to elucidate the climate variability impacts on living marine resources. Larval and juvenile stages are critical periods for the recruitment of living marine resources. However, limitations of observation methods for directly investigating the environments that larvae and juveniles experienced have been obstacles to our understanding. We reviewed the previous studies on climate variability impacts on living marine resources and discussed how reconstruction of environmental histories of larvae and juveniles is important for our understanding of climate variability impacts on living marine resources. We proposed a new, integrated method to reconstruct environmental histories of larvae and juveniles using otolith oxygen stable isotope analyses and fish growth-migration models. Together with the growth estimated from otolith daily increments, it is possible to elucidate climate impacts on larval and juvenile growth through environmental histories of larvae and juveniles using their realistic migration routes. This study was published on “Oceanography in Japan” in 2018.

June 2, 10:00/W6-Oral-12904

### Parametrizing climate-change responses of fished and cultured European aquatic species using experiments: A gap-analysis and meta-analytical perspective

Dominik Auch<sup>1</sup>, Pauline Kamermans<sup>2</sup>, Beatriz Morales-Nin<sup>3</sup>, Pedro Domingues<sup>4</sup>, Patricia Reglero<sup>5</sup>, Tina Sandersfield<sup>1</sup>, Natalie V. Angelopoulos<sup>6</sup>, Myron Peck<sup>1</sup> and Ignacio Catalan<sup>3</sup>

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Projections of the direct effects of climate-change (CC) such as increased warming, acidification and hypoxia on the physiological and behavior of fish and shellfish suggests that many fisheries and aquaculture species in European waters will undergo strong shifts in productivity. There is limited information, however, on the synergistic responses of the life stages of many species/stocks to climate-driven changes in temperature, pCO<sub>2</sub> (pH) and dissolved O<sub>2</sub>. We review the evidence from controlled laboratory studies on the direct effects of CC on the physiology, development and/or mortality of 32 commercial species of fish and shellfish across life-stages, regions and stressors, including freshwater and marine realms. A systematic literature review of published studies on freshwater and marine species important to fisheries and aquaculture highlighted a paucity of knowledge on the effects of multiple stressors on several life stages of the majority of species. A meta-analytical approach compared the strength and direction of responses of species to single and multiple abiotic stressors, revealing large differences even in related species. Although more controlled laboratory research is needed, existing knowledge suggests that fisheries and aquaculture industries will need to prepare to adapt to the direct and indirect effects of CC. Fisheries will need to adapt to shifts in species distribution and changes in seasonal phenology, while aquaculture will need to modify farming locations, practices or species. Advancing our understanding of multiple stressors on the responses of multiple species and life stages across regions to CC will ensure future opportunities for adaptation.

June 2, 10:15/W6-Oral-12993

### Development of a growth-migration model and its application to evaluate environmental effects on growth and migration of Pacific chub mackerel *Scomber japonicus* in the Northwest Pacific

Chenyang Guo and Shin-ichi Ito

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Pacific chub mackerel (*Scomber japonicus*) is a small pelagic and important commercial fish species widely distributed throughout the coastal areas of subtropical and temperate transition waters in the Indo-Pacific. However, its stock biomass and landings have shown large inter-annual variations in previous decades, which were considered to be potentially influenced by changing environmental variables including sea surface temperature, prey availability and ocean currents. To quantify the effects of those environmental factors on chub mackerel, we developed a growth-migration model. Growth characteristics were evaluated by a bioenergetics model, which parameters were estimated by reviewing previous studies except respiration-related term. The respiration parameters in the bioenergetics model and the cruising speed for a migration model were estimated by parameterizing the combined data, which consisted of swimming ability and metabolic data newly measured at 14°C using a variable speed swim tunnel respirometer, previous speed dependent metabolic data at 18 and 24°C and single speed (1 BL s<sup>-1</sup>) metabolic data at 15 and 20°C. As an application example, the established growth-migration model was used to simulate the early life history of 2010-year class individuals hatched at Apr 15th, 2010 in the Northwest Pacific under satellite derived environments. The model results showed significant difference of growth characteristic among the larval and juvenile groups characterized by different transport routes, indicating the importance of sea surface current on the distribution and fitness of chub mackerel in the early stage.

**June 2, 11:00/W6-Oral-13152**

### **Climate change effects on growth, reproduction and distribution of Norwegian Spring Spawning Herring**

Morten D. **Skogen**, Erik A. Mousing, Solfrid S. Hjøllø and Kjell Rong Utne

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The NORwegian ECOlogical Model system (NORWECOM.E2E) is an end-to-end ecosystem model under development for the Nordic and Barents seas, where a lower trophics NPZD model is two-way coupled to Individual Based Models (IBMs) for key species in the area. Using a downscaled RCP4.5 projection of the NorESM GCM, growth, reproduction and distribution of Norwegian spring-spawning herring and mackerel has been simulated and compared for present and future climate. Further, results from observed OA effects on copepod metabolism has been incorporated into the ecosystem model and simulations for a future low pH-ocean has been performed to study population effects of anticipated reduced growth for small copepodites at various spatio-temporal scales.

**June 2, 11:15/W6-Oral-13003**

### **Sensitivity of anchovy population to environmental change in the Bay of Biscay using a bioenergetic model**

Juan **Bueno-Pardo**<sup>1</sup>, Emmanuelle Dortel<sup>1</sup>, Susan Kay<sup>2</sup>, Pierre Petitgas<sup>3</sup> and Martin Huret<sup>1</sup>

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Anchovy of the Bay of Biscay is an important resource for pelagic French and Spanish fisheries. Due to their short lifespan, anchovy populations are strongly related to variations in recruitment and environmental “bottom-up” forcings. A model describing the population variations of anchovy in the Bay of Biscay has been implemented, rooted on an Individual Based Modelling with a Dynamic Energy Budget module capturing the full life cycle of anchovy individuals. Forcing for this model was provided by the physical-biogeochemical model POLCOMS-ERSEM, which was first used for validation using the time series between 2000 and 2016, and the known data on anchovy biomass and age structure from the stock assessment. The POLCOMS-ERSEM model was then run forced with IPCC climate scenarios RCP4.5 and RCP8.5 (+2 and +4°C average temperature increase respectively) over the period 2006-2099. The resulting time-series of temperature and zooplankton biomass, together with the current management strategy of the stock, were used to compare the population dynamics and bioenergetic condition of anchovy in the Bay of Biscay between the beginning and the end of the our century. This work integrates the information from a physical-biogeochemical model with a population model considering individual bioenergetics, making possible the interpretation of the results both from the perspective of populations and individuals. This duality makes finally possible to obtain conclusions on the evolution of the stock but also on the performance at the individual scale, which is a novel contribution in the management of this fishery in the Bay of Biscay.

June 2, 11:30/W6-Oral-12621

### Forecasting the effects of ocean change on Alaskan snow crab (*Chionoecetes opilio*) using an individual-based bioenergetics model

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Ocean change is forecasted to have the largest and most rapid effects at the earth's poles, with northern waters predicted to face the dual onslaught of rising temperatures and decreasing pH. The Alaskan snow crab (*Chionoecetes opilio*), a highly valuable target species, inhabits northern Alaskan waters and has been shown to have a narrow thermal tolerance. Research suggests other crabs species are sensitive to decreases in pH, particularly during early life stages, and the effects of warming and acidification may be synergistic. However, cumulative population effects of climate change on this species are difficult to predict, as crab sensitivity and exposure to changing ocean conditions varies with life stage. Here, we develop an individual-based, spatially-explicit, stage-structured model for snow crab to predict population response to ocean change. Future ocean conditions are forecasted across the Northern Bering, Chukchi, and Beaufort Seas using a regional ocean model forced by global climate projections. The DisMELS (Dispersal Model for Early Life Stages) framework predicts larval growth, mortality, and dispersal. A bioenergetics model forecasts temperature-dependent changes in growth of settled crab based on rates derived from experimental data. Reproductive processes (i.e. maturation, egg production, and hatching success) and molt timing also vary in response to changing temperature and pH. Warming waters are predicted to speed molt timing and increase size-at-maturity. Conversely, increasing metabolic costs result in higher starvation rates. Therefore, our results suggest a decrease in abundance but an increase in individual size of adult Alaskan snow crab under future climate scenarios.

June 2, 11:45/W6-Oral-13161

### Population models for synthesis of climate effects on fish early life history stages

Klaus B. **Huebert**<sup>1</sup>, R. Christopher Chambers<sup>2</sup> and Kenneth A. Rose<sup>1</sup>

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We are developing individual-based models to synthesize experimentally obtained data about climate change effects in fish eggs, larvae, and juveniles. These early life history stages can be particularly sensitive to ocean warming, acidification, deoxygenation, and other stressors. Our goal is to extrapolate from laboratory measurements (e.g., growth, development, and survival) to potential consequences for future fish populations. Currently we are focusing on the CO<sub>2</sub> and temperature effects on winter flounder (*Pseudopleuronectes americanus*), an economically important flatfish from coastal waters of the Northwest Atlantic. Our model framework tracks multiple generations of (super)-individuals from eggs until senescence, including their maternal lineage with potential for implementing trait heritabilities and therefore assessing adaptive responses to climate-based selective factors. For each year-class, a mechanistic young-of-the-year model simulates the ecophysiology of spawning and egg, larval, and juvenile development in detail. A representative sub-sample of survivors from the early life history stages is carried over to a separate population model, which simulates subsequent growth and mortality, but without additional climate effects. Model predictions include young-of-the-year stage abundances and durations, total annual spawning population abundance, age-structure, and recruitment. The model allows for quantifying CO<sub>2</sub> and temperature effects on annual dynamics and, cumulatively, over multiple generations.

**June 2, 12:00/W6-Oral-12609**

**Growth of teleost fish across marine regions and ecological lifestyles**

Daniël Van **Denderen**, Henrik Gislason and Ken H. Andersen

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How ocean warming will affect fish production depends critically on understanding how existing global temperature and prey resource variation affect fish growth. Here we aim to understand macroecological patterns in teleost fish growth from boreal to tropical regions, by collating von Bertalanffy growth data for fish with different ecological lifestyles. We show limited differences in growth within lifestyle across a large range of temperatures and prey availabilities (based on zooplankton and benthic biomass predictions). We find clear differences in growth across ecological lifestyle (*i.e.* pelagic, demersal and deep-sea demersal), yet average growth across lifestyles only differs by a factor of <4, while available prey biomass differs by a factor of >250. Following these observations, a fish growth and prey encounter model is used to hypothesize how fish vary in their feeding and maintenance characteristics. The model shows that 1) the temperature scaling of the maximum clearance rate needs to be lower than the scaling of metabolic rates, 2) not food-dependent growth but mortality might be a crucial element to balance energy budgets, and 3) demersal fish need on average a 10 times (and deep sea demersal a 50 times) higher maximum clearance rate than pelagic fish. The work describes a first attempt to mechanistically link prey densities and temperature to individual fish growth across habitats and ecological lifestyles. It highlights that our current understanding of how physiology and feeding ecology shape macroecological patterns is still incomplete, limiting current predictions of future fish and fisheries production in response to global change.

**June 2, 12:15/W6-Oral-12887**

**Sizing the effects of temperature on fish: A general eco-physiological model to assess impacts from individuals to ecosystems**

Philipp **Neubauer** and Ken H. Andersen

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Increasing temperature under climate change is thought to affect fish physiology through increases in metabolic demands, leading to decreases in body-size with concomitant effects on species ecology and fisheries. Although intuitively appealing, the magnitude, as well as when and where such changes should be expected remains controversial. To enable general predictions about temperature driven changes in fish size and ecology under climate change, we developed a trait-based eco-physiological model of temperature impacts on fish and other ectotherms. Our model disentangles the relative influence of thermal (metabolic) sensitivity, environmental conditions and species traits on ectotherm ecology and body size over ecological (plastic) and evolutionary time-scales. As an example, we contrast the thermal sensitivity of species on the trait spectrum between high and low food intake and activity (e.g., roaming predators vs sit-and-wait predators). By providing a general physiological explanation for temperature driven changes in species size and observed ecological consequences, our model ties together various strands of evidence about the ecological consequences of increased temperatures, and allows for a rigorous application of physiological constraints in ecosystem models.



## **W7: What do seabirds reveal about the effects of climate change on the World's Oceans?**

**June 3, 9:20/W7-Invited-12664**

### **Direct and indirect impacts of climate change on seabirds in the Benguela Ecosystem**

Richard B. Sherley

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Climate change is having both direct and indirect impacts on marine biodiversity. As marine endotherms that breed on land, seabirds need to satisfy a diverse range of conflicting requirements across their lives. At some point in their life cycle, most species are constrained in how far they can travel to find food, but climate change is altering the distribution and abundance of their prey. Many seabirds must also balance the apparently conflicting pressures of foraging in cold, productive waters – where they need sufficient thermal insulation to withstand rapid loss of heat to water – with nesting on land – where they may be exposed to rising temperatures. Others, breeding in cold climates, or during winter may have to cope with increasingly common storm-surges. I will summarize how climate change is affecting the endemic seabirds of the Benguela Ecosystem of Southern Africa. I will then focus on two specific examples of indirect and direct effect: how altered prey distributions drive penguin survival, and the direct effects of heat and storms on the breeding and thermoregulatory behaviour of cormorants. Finally, I will discuss some potential short-term mitigation strategies.

**June 3, 10:00/W7-Invited-12665**

### **North Sea seabirds: Responses to fisheries and changing climate**

Kate R. Searle<sup>1</sup>, Adam Butler<sup>2</sup>, Sarah Burthe<sup>1</sup>, Mark Newell<sup>1</sup>, Maria Bogdanova<sup>1</sup>, Richard Howells<sup>1</sup>, Francis Daunt<sup>1\*</sup> and Sarah Wanless<sup>1\*</sup>

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Seabird populations in the North Sea have shown substantial declines in recent decades. These populations are legally protected, and within UK and European statutory laws serve as indicators of environmental change in marine ecosystems as well as playing an important role in recreation and culture. It is widely considered that one of the main causes of these recent declines is changing climate. There is accumulating evidence from North Sea seabird populations that the effects of climate can be both indirect, via changes in food supply, and direct such as mortality from extreme weather events. Climate models predict an increase in mean temperature and in the frequency and severity of extreme weather events in the North Sea, therefore understanding the mechanisms underpinning seabird individual and population responses to changing climate is critical to effective management and mitigation. In this presentation, we will review case studies from the North Sea region linking declining seabird populations with changing climate, focusing on both changes to individual behaviour and fitness, and population level dynamics such as juvenile and adult survival and population productivity. We demonstrate that both short-term and long-term effects of climatic events and change are strongly linked to declining trends in many North Sea seabird populations, and identify where future research needs should be directed. Most critically, there is an urgent need to assess how warming temperatures affect the principal prey of seabirds in the North Sea; to determine the nature and potential escalation of climate change effects via interactions with other anthropogenic activities such as fishing, pollutants, disease, marine plastics, marine renewables, and ocean acidification; and to establish the role of phenotypic plasticity and micro-adaptation in enabling seabird populations to adapt to climate change.

**June 3, 11:10/W7-Invited-12674**

## **Demographic models and IPCC climate projections predict the decline of an emperor penguin population**

Stephanie Jenouvrier

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To predict birds population responses to future climate change, ecological forecast studies should combine ecological modeling approaches to climate models developed in the assessment report of the Intergovernmental Panel on Climate Change. I will detail such framework using the emperor penguin as an example. Studies predicting changes in population abundance and persistence have often been analyzed in terms of climate conditions at a particular location. For example, the Terre Adélie population of emperor penguins will decline from around 6,000 to only 400 breeding pairs by 2100. However, climate change will also produce changes in the spatial distribution of habitat quality. A species-level threat assessment study for the emperor penguin shown that at least two-thirds of the colonies are projected to become endangered by future sea ice decline by 2100. Dispersal processes should be also included in modeling framework because individuals may respond to climate change by moving permanently to other locations. For emperor penguins, dispersal behaviors can either offset or accelerate climate-driven population declines relative to a scenario without dispersal. In addition, I will discuss the factors affecting how useful ecological forecasts can be made by focusing on the different sources of uncertainties from climate (climate scenario, models and scales) to demography (environmental and demographic stochasticity, models and parameter uncertainties) and on various demographic approaches. A suite of new population modeling methods and remote-sensing products hold promise for reducing uncertainties associated with previous ecological projections and improving ecological predictability.

**June 3, 11:50/W7-Invited-13113**

## **Functional responses of marine birds to local and global changes in climate and prey availability**

Claire Saraux<sup>1</sup>, Robert Crawford<sup>2</sup>, Nicolas Courbin<sup>3</sup>, Andre Chiaradia<sup>4</sup> and William J. Sydeman<sup>5</sup>

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Most studies investigating the effect of climate change on seabirds focus on correlations between abiotic parameters and seabird life-history traits or population dynamics. Using penguins as indicators of the Southern Ocean, we showed for instance that sea surface temperature had an impact on penguin life-history traits, although the direction of those effects differed within species between traits as well as between species for a given trait. Other parameters such as wind or the Southern Oscillation index also affected penguins. Most of these effects were delayed, suggesting indirect effects of climate on penguins, probably mediated by prey abundance or accessibility. Prey thus appears to be the missing link to better understand and predict seabird's responses to climate change. Therefore, we then focused on the understanding of seabird – forage fish interactions using data from multiple ecosystems. Forage fish are well-known to fluctuate a lot especially in regards to different environmental conditions. Facing these fluctuations, seabird life-history seems to allow them to buffer their survival, while their breeding success is more affected. Further, because seabird diet might not be as plastic, seabird sometimes exert a high predation pressure on forage fish when forage fish stocks have already declined. Finally, inter-individual differences or plasticity in foraging behaviour can also help seabirds coping with fluctuant prey. For instance, we showed that shearwaters displayed highly different foraging areas from one day to another and between individuals. Investigating further how (1) the effect of climate and prey on single life-history traits and (2) inter-individual differences in responses might affect seabird population dynamics is of primary importance.

## **W8: Connecting climate, ocean and ecosystem observation – Ocean observation futures**

**June 3, 9:30/W8-Invited-13247**

### **Multidisciplinary Ocean Time Series: for researcher aggregation and the generation of surprises and knowledge**

Douglas **Wallace**

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Ocean time-series are usually justified in terms of utility for determining trends and patterns of change, or for identification of periodic components in data. Increasingly, they are argued to be essential for detection of climate-change-related trends in ocean properties. I will argue that multidisciplinary ocean time-series, where physical, chemical and biological properties are measured at seasonal or higher frequencies at a common location, have their greatest value in generating understanding of complex processes and event-driven phenomena. This utilizes the power of time-series data to reveal “intervention”, where an event or unusual forcing leads to a change, and of cross-correlation which can reveal relationships between multiple variables in order to explore processes. However of potentially greatest value is the ability of multidisciplinary time-series to encourage “researcher aggregation” across disciplines. The presentation will compare relative merits and strengths of ocean surveys vs. time-series for the development of biogeochemical and process understanding. It will draw on lessons learned (and “surprises” generated) at: the Cape Verde Ocean Observatory off West Africa; the Bedford Basin Time-Series near Halifax, Canada; and an emerging observatory in the Central Labrador Sea.

June 3, 10:00/W8-Invited-13242

## Implementation of biological Essential Ocean Variables in the global observing system

Patricia **Miloslavich**<sup>1,2</sup>, Nic Bax<sup>3</sup>, Daniel Dunn<sup>4</sup>, Samantha Simmons<sup>5</sup>, Ward Appeltans<sup>6</sup>, Valerie Allain<sup>7</sup>, Sonia D. Batten<sup>8</sup>, Lisandro Benedetti-Cecchi<sup>9</sup>, Sanae Chiba<sup>10, 11</sup>, Dan Costa<sup>12</sup>, J. Emmett Duffy<sup>13</sup>, Raphael Kudela<sup>14</sup>, Frank Muller-Karger<sup>15</sup>, David Obura<sup>16</sup>, Lisa-Maria Rebelo<sup>17</sup> and Yunne-Jai Shin<sup>18, 19</sup>

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<sup>9</sup> University of Pisa, Pisa, Italy

<sup>10</sup> UN Environment-World Conservation Monitoring Centre, Cambridge, UK

<sup>11</sup> JAMSTEC, Yokohama, JAPAN

<sup>12</sup> University of California Santa Cruz, Santa Cruz, CA, USA

<sup>13</sup> Smithsonian Institution, Edgewater, MD, USA

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<sup>19</sup> University of Cape Town, Cape Town, South Africa

Sustained observations of marine biodiversity and ecosystems are required by the international scientific, governance and policy communities to provide baselines to measure and mitigate the effects of human pressures and climate change. The Global Ocean Observing System (GOOS) identified Essential Ocean Variables (EOVs) based on their scientific and societal relevance and their technical feasibility. GOOS EOVs focus on the status and change of marine groups (phytoplankton, zooplankton, fish, marine turtles, birds, mammals), and of the cover and composition of keystone habitats (hard coral, seagrass, mangrove and macroalgae), with emerging microbial and benthic EOVs being defined ([www.goosoocean.org/eov](http://www.goosoocean.org/eov)). EOVs will link to Essential Biodiversity Variables (EBVs) through the Marine Biodiversity Observation Network (MBON) of GEO-BON.

Implementation plans are being drafted for each of the EOVs considering: (1) scientific and societal requirements and impacts, (2) current capabilities including methods, technologies, institutional and funding partners, (3) required actions to achieve the plan. Some implementation challenges are the lack of automation of measurements for most biological EOVs, limitations in monitoring capacity in many countries, the variety of methods used to measure the same variable, constraints in data sharing and timely deliver, and the need to effectively use and integrate associated biogeochemistry and physics measurements for a better understanding of community changes. Global implementation will require collaboration of the scientific and policy sectors and a significant commitment to improve human and infrastructure capacity across the globe, including the development of new, more automated observing technologies, and encouraging the application of international standards and best practices.

**June 3, 11:00/W8-Oral-12908**

### **Tara Oceans: Eco-systems biology at the planetary scale**

Matthew B. **Sullivan** and the Tara Oceans Consortium

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The ocean is the largest ecosystem on Earth and yet we know very little about it. This is particularly true for the plankton that drift within, even though they form the base of marine food webs and are key players in Earth's biogeochemical cycles. Ocean plankton are at least as important for the Earth system as the forests on land, but most of them are invisible to the naked eye and thus are largely uncharacterized. To increase our understanding of this underexplored world, a multidisciplinary consortium, Tara Oceans, was formed around the 110-ft research schooner Tara, which sampled plankton at more than 210 sites and multiple depth layers in all the major oceanic regions during expeditions from 2009-2013 (Karsenti et al. Plos Biol., 2011). This talk will summarize the first foundational resources from the project (see Science special issue May 22, 2015 and Nature 28 April, 2016) and their initial analyses, illustrating several aspects of the Tara Oceans' eco-systems biology approach to address microbial contributions to macro-ecological processes. The project provides unique resources for several scientific disciplines that are foundational for mapping ocean biodiversity of a wide range of organisms that are rarely studied together, exploring their interactions, and integrating biology into our physico-chemical understanding of the ocean. These resources, and the scientific innovations emerging to understand them, are critical towards developing baseline ecological context and predictive power needed to track the impact of climate change on the oceans.

**June 3, 11:30/W8-Oral-13066**

### **The World Ocean Database – Conjoining research observations and observing systems across disciplines, across time**

Tim **Boyer**<sup>1</sup>, Olga Baranova<sup>1</sup>, Scott Cross<sup>2</sup>, Carla Forgy<sup>1</sup>, Hernan Garcia<sup>1</sup>, Alexandra Grodsky<sup>1,3</sup>, Ricardo Locarnini<sup>1</sup>, Nazila Merati<sup>4,5</sup>, Alexey Mishonov<sup>1,3</sup>, Todd O'Brien<sup>6</sup>, Rost Parsons<sup>7</sup>, James Reagan<sup>1,3</sup>, Dan Seidov<sup>1</sup>, Igor Smolyar<sup>1</sup> and Melissa Zweng<sup>1</sup>

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Many of our historical and modern observations of the subsurface ocean come from large scale observing systems such as the Argo profiling float program. Many more stem from regional observing projects and individual research efforts. While the latter are usually for specific studies, the data are a valuable augmentation of observing system records for global and regional oceanographic and climate studies. The World Ocean Database (WOD) is an aggregation of historical and recent subsurface ocean profiles of physical (temperature, salinity), chemical (oxygen, nutrients, tracers) and biological (chlorophyll, plankton) measurements with uniform quality control and formatting, filling the role of Center for Marine Meteorology and Oceanographic Climate Data for ocean profile data in the JCOMM Marine Climate Data System Historical data (some in WOD dating from before 1800) are imperative for assessing modern data in the context of ongoing climate change. Bringing together operational monitoring system measurements and data from research institutes, national data centers, and individual investigators, provides ocean and climate researchers an invaluable data set across disciplines than any individual study or operational system is capable of alone. Further, ecosystem and climate change impact studies will be facilitated by cooperative efforts such as those between the WOD and the COPEPOD plankton database, whose expanded plankton observations will be available in WOD format alongside relevant co-sampled physical and chemical measurements. The contents of the WOD, quality assurance procedures, data accessibility, standards and formats, integration and cooperative work, are discussed along with future direction and enhancements.

## **W9: Vulnerability of Low Elevated Coastal Zones (LE CZ) to SLR in changing oceans**

**June 2, 9:15/W9-Invited-13252**

### **The risk of inundation by sea level rise: The Nile Delta**

Mohamed Abdel-Karim Aly **Abdrabo**

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The Nile Delta is densely populated areas, which accommodates significant proportion of Egypt's economic activities and built-up areas. Large areas of its coastal areas are projected to be inundated by sea level rise (SLR). Accordingly, the Delta has been examined in several studies, which worked under various global and hypothetical SLR scenarios and provided different estimates of areas susceptible to inundation due to SLR. A study, conducted with the support of Alexandria Research Center for Adaptation to Climate Change (ARCA), intended for the first time to downscale global SLR scenarios to the Egyptian coastal areas along the Mediterranean found SLR in the area to be lower than that of the global ones by 10-20 cm up to the year 2100. Additionally, another piece of research conducted ARCA staff, to update a digital elevation model for the coastal areas of the Nile Delta, provided a more precise and realistic model for the area.

These new findings, necessitates a revisit to the coastal vulnerability of the Nile Delta coastal areas. The results show the extent to which less than reliable data can do to vulnerability studies of coastal areas to SLR.

**June 2, 11:00/W9-Oral-12348**

### **Potential increasing coastal inundation over Semarang city based on twelve years tide observations**

Furqon **Alfahmi**

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One of the impacts of climate change is the rise of sea level. In annual variability, sea level rise will also interact with La Nina events. Because the warming of sea surface temperature in Indonesian maritime continent during La Nina events, sea surface levels increase. Monthly highest tides had been observed for 12 years. The correlation between the monthly highest tides with Southern Oscillation Index (SOI) is about 0.5. The monthly highest tides increased 4 to 16 cm on the La Nina events compare three month before. Potential coastal flood has been simulated by hydrodynamics modeling for each category of SOI. The result show that the flooding area for SOI <7.7 approximately <2% of the area of Semarang city while SOI values >7.7 lead to flooding >2%.

**June 2, 11:30/W9-Oral-12608 (CANCELLED)**

**Assessing attitudinal response and perception of the threat of sea level rise: A case study of the coastal area of the Niger Delta**

Ikechuwku **Mbachu** and Isa Olalekan Elegbede

Chair of Environmental planning, Brandenburg University of Technology, Cottbus-Senftenberg. E-mail: talk2iyke@yahoo.com

Sea Level Rise (SLR) is a major challenge facing the coastal Niger Delta region of Nigeria. Understanding public perception on SLR and the reasons behind such perception is essential to the design of effective policies and public acceptance of such policies. There is a dearth of studies on public perception in the Niger Delta. The study investigates expert and public perceptions to the impacts of SLR and the implication of these perceptions on sustainable adaptive mechanisms to SLR in the Niger Delta. Based on previous studies and geospatial modelling, current and projected hotspots of SLR in the Niger Delta were identified. Proportionate stratified random sampling method was employed to select respondents for questionnaire administration. Questionnaires were analyzed using the Xlstat tool. Expert perception was investigated through semi-structured interviews. A comparative analysis of responses was conducted to examine the perceptual congruence between both classes of respondents. Regression analyses were employed to explore the relationships between different themes under investigation. Principal component Analysis method was used to determine the major factors underlying public perception. Results reveal that perceptions are mainly influenced by education, income and occupation. In comparison with other environmental challenges in the Niger Delta Coastal area, there is a very low level “sense of urgency” attached to SLR in the Niger Delta. Most of the respondents do not regard SLR as a “present danger”. There is a need for more concerted efforts towards enlightening and greater engagement of the public in policy formulation geared towards combating SLR.

**June 2, 12:00/W9-Oral-12603**

**A scenario-based approach to assessing changes in coastal flood magnitude and frequency under a changing climate, with an exemplar application to ecosystem vulnerability assessment on the Island of Hawai’I**

John J. **Marra**<sup>1</sup>, Ayesha S. Genz<sup>2</sup>, William V. Sweet<sup>3</sup>, Lisa Marrack<sup>4</sup> and Chad Wiggins<sup>5</sup>

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Coastal flooding and erosion attributable to sea level extremes result from a variety of processes. As a result, estimates of future coastal flood potential must account for patterns of sea level variability and storminess as well as global and regional sea level rise. A scenario-dependent framework for the formulation of estimates of future coastal flood potential includes *Extremes Analysis*, *Local Sea Level Trend Analysis*, and *Climate Sensitivity Analysis* (Marra et al., 2015). Using this approach, a series of analyses were conducted to evaluate how coastal flood magnitude and frequency might change along a section of shoreline on the Island of Hawai’i in response to such sea level change. The results of these bounding analyses indicate that changes in flood magnitude over the next 30 years or so are relatively small, on the order of one to two-thirds of a meter (1-2 feet), regardless of the GMSL scenario. Where effects are most likely to be felt is changes in flood frequency. Owing to the nature of the factors affecting coastal flooding along this segment of shoreline, increases on the order of 10 or 20cms in water level elevation were found to correspond to considerable changes in the flood frequency. What were relatively rare events will quickly become relatively common. Similar observations have been reported elsewhere (Sweet and Marra, 2014; 2015). One application of these results was an assessment of potential impacts to unique anchialine pool ecosystems along the Kohala and Kona Coasts on the Island of Hawai’i.

## W10: Intercomparison of fisheries and marine ecosystem models

June 3, 9:10/W10-Oral-13224

### FishMIP: A community effort to improve the realism and utility of fishery and marine ecosystem models

Eric D. Galbraith<sup>1,2</sup>, Heike Lotze<sup>3</sup>, Derek Tittensor<sup>3</sup>, Olivier Maury<sup>4</sup>, William W. L. Cheung<sup>5</sup> and Tyler Eddy<sup>5</sup>

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Many rapid changes are occurring in the oceans, with significant impacts on the health of the marine ecosystem and its ability to provide nutritious food to humans. Numerical modeling offers an important tool for assessing these changes, and identifying possible solution spaces. However, the marine ecosystem is complex, and comprehensive models remain in their infancy. The Fisheries and Marine Ecosystem Model Intercomparison Project (FishMIP) was created with the aim of providing a platform for discussion and quantitative comparison between models, and to produce multi-model syntheses for stakeholders. FishMIP has thus far produced a comprehensive overview of the existing model types, which includes a rich diversity of conceptual and practical approaches, and has generated a first set of future projections based on a unified set of climate-model forcings. But the potential of FishMIP goes well beyond this. Future simulations will include test scenarios using high-resolution regional domains where high quality ecosystem data is available for comparison, idealized forcing scenarios to explore model contrasts and improve mechanistic representation, and future scenarios of global fishing effort. Most importantly, FishMIP is a community-oriented effort that strives to be inclusive, and new participants are encouraged to join at any time.

June 3, 9:35/W10-Oral-12899

### Climate change impacts on fish biomass and associated ecosystem structure across ocean basins

Andrea Bryndum-Buchholz<sup>1</sup>, Heike Lotze<sup>1</sup> and Derek Tittensor<sup>1,2</sup>

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Climate change impacts on marine ecosystems include global and regional changes in primary production, species distributions and abundances. These will result in significant consequences for marine ecosystem structure and functioning, as well as socioeconomic impacts on fisheries and fishery-dependent societies. Yet how these changes may play out over the coming century on an ocean-basin scale remains largely unknown, and projections from single ecosystem models do not adequately capture the full range of projection uncertainty. We use multiple marine ecosystem models within the Fisheries and Marine Ecosystem Model Intercomparison Project (Fish-MIP) framework to analyze regional responses in marine consumer biomass to historical and projected future climate change scenarios. Under a high emissions scenario (RCP 8.5), total fish biomass declined by a multi-model mean of 15-30% in both temperate and tropical ocean basins by 2100, whereas polar basins experienced a 20-80% increase. Furthermore, we show that under low (RCP 2.6) and high (RCP 8.5) emissions scenarios in all ocean basins - from the Pacific to the Atlantic, and the Indian to the Polar Oceans - ecosystem structure drastically changed by the end of the 21st century. Our study represents one of the first analyses of climate change impacts on fish biomass and marine ecosystem structure at an ocean basin scale using an ensemble of marine ecosystem models, and can inform marine resource management and policies on regional, policy relevant scales.



**June 3, 9:55/W10-Oral-12987**

## **Projecting climate change & de-oxygenation impacts on global oceanic communities using NEMO-PISCES-APECOSM**

Olivier **Maury**<sup>1</sup>, Olivier Aumont<sup>2</sup>, Nicolas Barrier<sup>3</sup> and Laurent Bopp<sup>4</sup>

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Climate changes are modifying oceanic ecosystems at an unprecedented and increasing speed, potentially pushing them towards radically different states with no analogues in the past. In this context, modeling is of prime importance to infer potential future changes and identify processes at stake. We use the NEMO-PISCES-APECOSM model coupled to the IPSL-CM5 Earth System Model along the IPCC scenario RCP8.5. The IPSL-CM5 represents the major dynamical, physical and bio-geochemical processes of relevance in the climate system. It includes an OGCM model (NEMO) and an ocean biogeochemistry model (PISCES) that are used to provide environmental (temperature, currents, light, oxygen) and trophic (two sizes of phytoplankton, two sizes of zooplankton, two sizes of particulate organic matter) forcing to the upper trophic level model APECOSM. APECOSM represents the 3D dynamics of size-structured generic pelagic communities (epipelagic, mesopelagic, migratory and bathypelagic) in various biomes (tropical, temperate and polar) of the global ocean. It represents size-structured trophic interactions; individual bioenergetics based on DEB theory; physiology and behavior (3D movements, schooling) and includes the effects of life-history diversity in communities. We analyze how the effects of future climate-induced changes on both physical and biogeochemical variables might affect the diversity, abundance, seasonal dynamics, horizontal distribution and vertical extension of major oceanic communities and how this would affect ecosystem functions in terms of energy fluxes, material uptake and export and trophic interactions between communities in different major biogeographic regions of the ocean.

**June 3, 10:15/W10-Oral-13115**

## **The Princeton Ocean Ecosystem Model (POEM) v2.0: a size- and functional type-based model of global fisheries production and catch**

Colleen M. **Petrik**<sup>1,\*</sup>, Ken H. Andersen<sup>2</sup>, Charles Stock<sup>3</sup>, Daniël Van Denderen<sup>2</sup> and James Watson<sup>4</sup>

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The Princeton Ocean Ecosystem Model (POEM) version 1 (v1.0) has been included in the initial list of models in the FISH-MIP protocol paper. This talk will present in detail the latest version (v2.0) of POEM. Version 2.0 completely restructured the mechanistic model, taking it from a size-based model to a composite (hybrid) model. It now represents 3 different fish functional types, the full life cycle of each functional type based on metabolic scaling principles, and the trophic interactions between the fishes and with their pelagic and benthic food resources. We constructed POEMv2.0 to be a simple, dynamic, and mechanistic global model of commercially important fishes, the fish equivalent of a Nutrient-Phytoplankton-Zooplankton (NPZ) model. Our goals for the model were that it would (1) represent differences in life history, habitat, maximum size, and feeding preferences, (2) simulate competitive and predatory interactions, (3) simulate the full life cycle without relying on a stock-recruitment relationship, and (4) be temporally dynamic to be able to capture tipping points and/or regime shifts. It is currently coupled to the Carbon, Ocean Biogeochemistry, and Lower Trophics (COBALT) version 1.0 marine ecosystem model developed by the Geophysical Fluid Dynamics Laboratory that provides the physical and biogeochemical environment and planktonic food web dynamics. We will present a contemporary simulation as well as information on the inputs needed and potential outputs for comparison with other models.

**June 3, 11:10/W10-Invited-13218**

## **Shared Socioeconomic Pathways (SSPs) for fisheries and aquaculture in Europe**

John **Pinnegar**<sup>1,2</sup>, Katell G. Hamon<sup>3</sup> and Myron Peck<sup>4</sup>

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<sup>2</sup> School of Environmental Sciences, University of East Anglia (UEA), Norwich, UK

<sup>3</sup> Wageningen Economic Research, The Hague, The Netherlands.

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Climate change is anticipated to have long-term and widespread consequences for the fisheries and aquaculture sectors of Europe, however other human factors such as the intensity of fishing, the construction of offshore windfarms, the spatial management of marine and inland waters and the price of fuel and fishmeal can also affect how these industries develop. For modelling efforts to be successful it is necessary to consider how such factors might change in the future and their interaction with climate variables. In this study, four socio-political scenarios were developed, based partly on the IPCC SRES (Special Report on Emissions Scenarios) framework and partly on the new system of Shared Socio-economic Pathways (SSPs). For each CERES scenario, a set of quantitative outputs has been generated. Specifically, projections are provided for human population growth, per capita fish consumption, national affluence and therefore, demand for fish and shellfish products at the European level. Scenarios are neither predictions nor forecasts of future conditions. No single scenario will ever come true in its entirety. The CERES socio-political scenarios will be used, to evaluate the relative impacts of climate change versus management of other human pressures on wild-capture fisheries, freshwater and marine aquaculture throughout the European continent. We provide examples of how these scenarios have been 'regionalized' for applications in the North Sea and we argue that it would be beneficial if a similar framework could be adopted elsewhere in order to facilitate cross-comparison and communication of results.

**June 3, 13:30/W10-Oral-13178**

## **A predictive fisheries catch metric for CMIP6-OMIP Earth System models**

Cheryl S. **Harrison**<sup>1</sup>, Samantha Stevenson<sup>2</sup>, Nicole Lovenduski<sup>1</sup> and Jessica Luo<sup>3</sup>

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Observed fisheries catch in large marine ecosystems (LMEs) have been empirically linked to observed rates of secondary production and benthic detrital flux, resulting in the development of fisheries catch metrics that have high predictive skill for an Earth system model with validated representation of secondary production, with the best performing metric relying on productivity rates of mid-to-large zooplankton (Stock et al., 2017). However, most Earth system models do not simulate multiple zooplankton types, nor is zooplankton production a standard model output variable in the upcoming 6th Climate Model Intercomparison Project (CMIP6) Ocean Model Intercomparison Project (OMIP). Here we modify the Stock et al. 2017 fish catch metrics to use variables available in CMIP6-OMIP simulations, resulting in comparable predictive skill. This predictive catch metric is then applied to the Community Earth System Model (CESM), including the CESM Large Ensemble, to explore the effects on climate variability on fisheries catch across the global LMEs.

**June 3, 14:10/W10-Oral-13226**

## **Projecting climate change impacts on regional marine ecosystems using OSMOSE**

Ricardo **Oliveros-Ramos**<sup>1</sup> and Yunne-Jai Shin<sup>2</sup>

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We use the marine ecosystem model OSMOSE to forecast the impact of several scenarios of climate change, using the Northern Humboldt Ecosystem as case study. The OSMOSE model is forced by plankton production from IPSL CM5A-LR and GFDL-ESM2M models for the period 2006-2100. For each model, representative concentration pathways (RCP) scenarios 2.6, 4.5, 6.0 and 8.5 are considered. We describe the issues around the use of global Earth System Models (ESM) as forcing for regional marine ecosystem models, and propose a solution based on the statistical downscaling and bias correction of ESM outputs. We also highlight the importance of a careful and realistic implementation of the impacts of fishing in the model to explain future variability in fish production, particularly since the “business as usual” scenarios are unlikely and changes in fisheries dynamics are expected as result of socio-economic interactions.

**June 3, 14:30/W10-Oral-12817**

## **Fisheries and marine ecosystem projections under climate change from regional to global scales**

Tyler **Eddy**<sup>1,2</sup>, Heike Lotze<sup>2\*</sup>, Derek Tittensor<sup>2,3</sup>, Andrea Bryndum-Buchholz<sup>2</sup>, William W. L. Cheung<sup>1</sup>, and Eric D. Galbraith<sup>4,5</sup>

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Due to limitations in computing power, global climate models are often not well enough resolved to represent fine scale coastal processes such as eddies and upwelling that control nutrient flow and primary production. As a result, there are often discrepancies in projections by regional fisheries and marine ecosystem models compared to projections by global models for the same regions. While most global fisheries and marine ecosystem models agree in the projected direction of change in fish production given a specific climate model and emission scenario, regional models often project the opposite direction of change. In order to understand the sources of variation in fisheries projections for global to regional models, we make comparisons of:

1 - Regional models forced by global climate data & subsets of the corresponding model region from global models forced by global climate data

2 - Regional models forced with regional climate data (ROMS) compared to when forced with global climate data

3 - Subsets of global models forced with regional climate data (ROMS) compared to when forced with global climate data

**Keywords:** climate change, ecosystem models, fisheries.

**June 3, 14:50/W10-Oral-13228**

**Comparing climate forcing projections from global and local climate models in south-eastern Australia using an EwE model**

Catherine Bulman, Elizabeth **Fulton**, Xuebin Zhang and Richard Matear

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For the first stage of the FISHMIP collaborative project, we used representative concentration pathway (RCP) projection data from several global climate models to force primary production in the Ecopath with Ecosim (EwE) models. In south-eastern Australia, we employed the East Bass Strait EwE model, developed nearly a decade ago and based on detailed biological surveys of this area. One of the original purposes for the construction of this model was to investigate the impact of climate change based on a forcing function of declining primary production rates assuming that sea temperatures would increase by about 2°C over the next few decades. It was also used in a 2012 collaborative project of Australian EwE models investigating the of impact climate change more broadly in Australia. The forcing functions employed in that project were based on projection data from the CSIRO MK3 global model that was relevant only for large oceanic areas and recognised as being inadequate for the relatively coastal regions of Australia. Since then, global climate model projections have no doubt improved and were used in the FISHMIP exercise. But it was not until the projections became available from an OFAM-3 model, downscaled specifically for the Australian coastal regions, could we be more certain that the oceanographic nuances in our coastal regions could be better captured and modelled. Here we present some model details, and the comparison of simulations using the original FISHMIP forcing functions and those derived from our “local” climate model projections.

**W11: Quantifying thresholds in driver-response relationships to identify reference points**  
**PICES Working Group 36 (CERP) workshop**

**June 3, 9:00/W11-Invited**

**Quantifying critical points in ecological indicator responses to fishing and the environment**

Scott **Large**

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Ecosystem-based fisheries management (EBFM) is a more holistic management strategy that concurrently addresses human, ecological, and environmental factors influencing living marine resources and evaluates these considerations collectively on a system level. Ecological indicators seek to develop decision criteria for EBFM as keyed to quantifiable attributes of ecosystem status. For EBFM, indicator reference points associated with management action need to be quantified, analogous to single species decision criteria (e.g., BMSY). Ecological indicator thresholds would in principle capture responses to both fishing and environmental pressures. Theoretical and quantitative methods have been developed to assign decision criteria to ecological indicators' response to human-use pressures; yet few efforts have established decision criteria in response to the combined influence of human-use and environmental pressures. Here, we seek to identify ecological thresholds at which a small change in fishing and environmental pressure results in an abrupt change in ecosystem status. We applied multiple analytical techniques including bivariate generalized additive threshold models and gradient forest models to determine more broadly (i.e., with global and national representation) if ecological indicators have common inflection points in response to fishing and environmental pressures. Our findings highlight levels of pressure where the magnitude of indicator response might differ from our expectations.

## POSTER PRESENTATIONS

### Observers:

#### Observer-CAS

#### **Facing the future: Center for Ocean Mega-Science, Chinese Academy of Sciences**

Fan **Wang**

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Contemporary marine sciences are multi-disciplinary, ambitious, heavily funded, and possess large-scale facilities, clear indicators of Mega-Science. An overview of the world's major powers in marine science and technology suggests that these countries share clear national objectives and celebrate the intersection and integration of various disciplines, thus forming comprehensive marine research facilities that adapt to the requirements of research in Mega-Science. The Chinese Academy of Sciences (CAS) relies heavily on its Institute of Oceanology and uses “the integration of its Institute of Oceanology and its Yantai Institute of Coastal Zone Research” and “the integration of science and education” as major vectors, utilizing expedition fleets, the regional centers of fundamental instrument in marine sciences, field observing networks, and large-scale data centers as its main support, finally establishing the Center for Ocean Mega-Science (COMS), CAS in 2017. The center constitutes an innovative platform of science and technology that enables open and efficient sharing, offers an advantageous training site for elite personnel in the marine sciences, and serves as a research center with international influence, facilitating collaborative innovations domestically and abroad. The center is poised to introduce the “healthy ocean” demonstration project, the Indo-Pacific convergence zone, and marine life processes and green biological resources, developing above three core research modules comprising multi-spherical interactions. The center is committed to enhancing awareness and understanding of regional and global marine issues and developing innovative solutions, producing world-class influential results that will serve as important technological support for the implementation of domestic and international ocean strategies.

#### Observer-NPAFC

#### **Salmon and people in a changing world: Introducing the International Year of the Salmon**

Mark Saunders<sup>1</sup>, Madeline Young<sup>1</sup> and Suam **Kim**<sup>2</sup>

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The International Year of the Salmon (IYS) is a unique opportunity for the peoples of the Northern Hemisphere to “sign up for salmon” in order to emphasize and explore the close link between the health of the planet and these iconic species. The North Pacific Anadromous Fish Commission (NPAFC) and the North Atlantic Salmon Conservation Organization (NASCO) invite everyone—from schoolchildren to scientists and political leaders—to participate in research and outreach activities focusing on the relationship between salmon and people. Starting in late 2018 through to 2022, these activities will search for ways to understand and minimize the impact of climate change and other threats to salmon while celebrating the importance of these ancient and international animals. Teams of experts will be brought together under each IYS theme (status of salmon, salmon in a changing salmosphere, new frontiers, human dimension, information systems and outreach and communication) to consider ideas for innovative projects that will bring about measurable change. A Signature Project in the North Pacific aims to bring salmon research back to the high seas through a coordinated effort of multiple countries during the winter. Salmon Connections is another concept under development that aims to quantitatively describe and predict salmon production in the ocean within a model framework facilitating regional comparisons between and within oceans. Beyond targeted outreach and research projects, there is something for everyone in the IYS. If interested in learning more or becoming involved, please contact the NPSFC Secretariat at secretariat@npafc.org or the NASCO Secretariat at [hq@nasco.int](mailto:hq@nasco.int).

## **S1: Ocean extremes and their impact on marine ecosystems**

### **S1-P1**

#### **“El Niño Costero” 2017 in Niño 1+2 or the Carnival Coastal Warming event?**

Franklin Isaac [Ormaza-González](#) and Jonathan M. Cedeño

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During February, strong trade winds from the Caribbean Sea blew through Panama Bay and pushed surface waters (SST up to 29.8°C) southward (to El Niño 1+2) producing a strong upwelling and negative SST anomalies (down to -3°C), this in turn produced a rapid, short lived but intense warming of the surface waters from February to March 2017; whilst at the same time the ONI index was -0.4°C. The sudden warming originated anomalies up to +2.6°C (15 March); *i.e.* over 29.1°C, at the same time in 3.4 the anomaly was -0.1°C. The ZCIT moved quickly southward from 4-5N to 8S, and remained there for 4-6 weeks provoking a sort of greenhouse effect. The average rain (Jan-Apr 1980-2010) in Ecuador coast (6 stations) is 4391.5 mm, whilst in 2017 was 4312.3 mm. The SOI was +0.22 (Jan-May), and 0.9 in March. Thermocline did not deepen below 30 m, during El Niño it is under 100 m. Sea levels anomalies were static around 5 cm, but during El Niño 1997-1998 were over 40 cm. Fisheries were not evidently affected, in fact they grew >82% in the first semester, mainly the anchovy. The Ecuadorian fleet catches of Skip jack (*Katsuwunnus pelamis*), Yellow fin (*Thunnus albacares*) and Big eye (*Thunnus obesus*) were 17.5, 8.3 and 50.6% respectively higher than same 2016 period. By mid-May anomalies in 1+2 fell to 0.4°C and there was a quick cooling down process. To name this event as “Niño Costero” is incorrect and brings erroneous and confusing response from society. Hereafter, analogously to the term “El Niño” it is proposed to call this phenomenon “Carnival Coastal Warming” or simply the “El Carnaval”, as carnival festivities are in February-March.

### **S1-P2**

#### **New Zealand fisheries and climate change effects on the ocean: A wake up call**

Mary [Livingston](#), Vonda Cummings, Cliff Law, Matt Pinkerton and Darren Parsons

Ministry for Primary Industries, Fisheries Science, Wellington, New Zealand. E-mail: Mary.Livingston@mpi.govt.nz

Climate change effects on the ocean and variability extremes are beginning to bite in New Zealand, which means that government practitioners are absorbing the notion that climate change is already here, affecting fisheries now, rather than something that may happen in the future. Sorting out trends from variability with short time series has hampered progress, but since the 2014 PICES meeting in Santos we have developed indicators of specific risk to fisheries and identified areas of risk in our EEZ. The marine heatwave in the Tasman Sea December 2017 brought unprecedented increases of 6 degrees C above average to several areas of New Zealand waters and has helped to focus our attention on the role of the sea conditions not just on fisheries but to the land as well. I will be updating delegates on what climate change research and management actions we are developing in New Zealand to inform our stakeholders on what lies ahead.

### S1-P3

#### **Extreme and abrupt changes of water temperature and their fisheries impacts in the East Asian Marginal Seas**

In-Seong **Han**, Ju-Yeon Kim and Joon-Soo Lee

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The East Asian Marginal Seas is known as the region with the one of highest increasing rate of SST (Sea Surface Temperature) in the world. Actually, SST in the East Asian Marginal Seas was increased about 1.09°C during last 100 years, especially SST around the Korea Peninsula was increased about 1.25°C during last 50 years. These increasing trends were more 2.5 times than the increasing trend of SST in the global. In addition to these high increasing trends of long-term SST, extreme and abrupt changes of SST appeared around these areas in recent. In summers 2016 and 2017, SST around the Korea Peninsula was higher 2~7°C than mean values. The reasons of these extreme positive SSTA (Sea Surface Temperature Anomaly) is thought to be the influence of strong North Pacific High Pressure, strong Tsushima Warm Current and absence of Typhoons in July and August these years. During winters in 2010~2012, on the other hands, extreme low SST appeared around the Korea Peninsula. Significant negative SSTA, which was lower 2~4°C than mean values, should be caused by negative AO (Arctic Oscillation) index due to Arctic warming and Ural Blocking, strong Siberian High Pressure and La Niña events. These extreme and abrupt SST changes caused the mass mortality of aquatic organisms. Actually, fisheries economic damages around the Korea Peninsula were estimated about a few hundred million USD during last a few years by abnormal water temperature conditions.

### S1-P4

#### **Ecological traps in shallow coastal waters – Potential effect of heat-waves in tropical and temperate organisms**

Catarina **Vinagre**, Vanessa Mendonça, R. Cereja, F. Abreu-Afonso, M. Dias, D. Mizrahi and Augusto A.V. Flores

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Mortality of fish has been reported in tide pools during warm days. That means that tide pools are potential ecological traps for coastal organisms, which happen when environmental changes cause maladaptive habitat selection. Heat-waves are predicted to increase in intensity, duration and frequency, making it relevant to investigate the role of tide pools as traps for coastal organisms. However, heat waves can also lead to acclimation. If organisms undergo acclimation prior to being trapped in tide pools, their survival chances may increase. Common tide pool species (46 species in total) were collected at a tropical and a temperate area and their upper thermal limits estimated. They were maintained for 10 days at their mean summer sea surface temperature +3°C, mimicking a heat-wave. Their upper thermal limits were estimated again, after this acclimation period, to calculate each species' acclimation response. The upper thermal limits of the organisms were compared to the temperatures attained by tide pool waters to investigate if 1) tide pools could be considered ecological traps and 2) if the increase in upper thermal limits elicited by the acclimation period could make the organisms less vulnerable to this threat. Tropical tide pools were found to be ecological traps for an important number of common coastal species, given that they can attain temperatures higher than the upper thermal limits of most of those species. Tide pools are not ecological traps in temperate zones. Tropical species have higher thermal limits than temperate species, but lower acclimation response, that does not allow them to survive the maximum habitat temperature of tropical tide pools. This way, tropical coastal organisms seem to be, not only more vulnerable to climate warming per se, but also to an increase in the ecological trap effect of tide pools.



## S1-P5

### **Integrated index of stress responses to a future marine heat wave in tropical intertidal organisms**

Carolina Madeira<sup>1,2</sup>, Vanessa Mendonça<sup>1</sup>, Miguel C. Leal<sup>1,3</sup>, Augusto A.V. Flores<sup>4</sup>, Henrique N. Cabral<sup>1</sup>, Mário Diniz<sup>2</sup> and Catarina **Vinagre**<sup>1</sup>

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Tropical and subtropical reef associated organisms have been recognized as being among the most vulnerable organisms towards environmental change, namely due to extreme climatic events associated with global warming. The study of their physiological responses under environmental stress seems to be a key issue for assessing ecosystem health in these areas but this knowledge is still missing for most species. In this study, we examined the effects of a laboratory simulated heat wave on the physiology and performance of four tropical shallow water Atlantic species, including fish, crustaceans and gastropods. We exposed the animals to a future average temperature and a heat wave temperature during one month and analyzed molecular and energy biomarkers, as well as body condition and mortality, using an integrated index of physiological responses. Results suggest that the heat wave elicited a cellular stress response in all species, as shown by higher scores obtained in index calculations when compared to control conditions. These higher index values are also suggestive of a poorer health status in individuals subjected to the heat wave simulation, in spite of their acclimation ability. Highest biomarker fold-changes were detected in protective chaperones and antioxidants, indicating the occurrence of thermal and oxidative stress, likely due to higher metabolic rates and O<sub>2</sub> consumption. Additionally, significant changes in body condition were only detected for the two fish species. Mortality rates of all species remained unchanged during the heat wave. We conclude that these Atlantic species are capable of physiological adjustments in response to rapid environmental changes, which ultimately confers them with enough thermal tolerance to withstand future heat waves with some energy tradeoffs but without major consequences on performance.

## S1-P6

### **Comparing NOAA Coral Reef Watch regional satellite monitoring and in-water observations to prepare for repeat coral bleaching events in a warming world**

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The 2014-2017 global coral bleaching event was the longest, most widespread, and most damaging coral bleaching event on record. Many tropical reef locations experienced consecutive years of heat stress, causing greater overall coral mortality and impeding recovery. Guam, in particular, experienced severe, widespread bleaching in 2013, 2014, 2016, and 2017 (worst bleaching on record), as well as localized bleaching due to El Niño-associated low sea level in 2015. Other locations in the equatorial Pacific, such as Kiritimati and Jarvis Island, experienced single heat stress events lasting up to a year (cf. usual 3-4 months). NOAA Coral Reef Watch's (CRW) satellite bleaching alert and modeled outlook products were critical in monitoring, predicting, and assisting analyses as these events unfolded, and assisted in identifying coral reef areas experiencing multiple bouts of heat stress. CRW recently extended its 5km satellite-based global sea surface temperature dataset back to January 1, 1985 with the release of CoralTemp. Using Guam, Kiritimati, and Jarvis Island as examples, we compared regional bleaching heat stress measurements derived from CoralTemp with *in situ* bleaching records from local reefs to see how the frequency and severity of heat stress events have changed through time in these regions. These locations provide a credible precursor case study of the effects that rapid-return, long-duration climate-driven marine heatwaves can have on coral reef ecosystems. In a warming world where mass coral bleaching is becoming more frequent, this information is critical to informing policy changes that can help the world's remaining coral reefs survive.

## S1-P7

### Effects of elevated temperature as climate change stressor on physiological responses and survival of the coralline alga *Corallina officinalis*

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This communication will analyse the adaptation capability to climate change stressors of a South East UK population of *Corallina officinalis*. This species has a worldwide distribution, living in the lower and mid-littoral zones on rocky shore and in rock pools. It is well adapted to thermal excursions, and because of the higher growth rate compared to other coralline algae, it is a good experimental model for climate change studies. In particular, the work is aimed at understanding how this species, already adapted to survive to wide thermal excursions, would respond both to gradual ocean warming and to marine heatwaves increased in intensity and frequency under anthropogenic climate change. The research focuses on the effects of increased temperature on metabolic processes (*i.e.*, respiration, photosynthesis, calcification), growth rate, and survival of this population. Preliminary results, confirming a general negative effect of thermal stress on these metabolic processes, will be reported. The analysis carried out, combining the effects of thermal stress induced by tides, gradual ocean warming and marine heatwaves, could represent a useful contribution to the current researches aimed at predicting how climate change will impact marine ecosystems.

## S1-P8

### Peek into the future: Extreme physical oceanographic condition in Alaskan Waters from CMIP5 simulations

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Extreme conditions are quantified by probability distribution functions (pdfs) of physical oceanographic conditions in Alaskan waters during the next 50 years using output from the Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations. Our analysis considers separately four different habitats: the southeast Alaska panhandle, western Gulf of Alaska, southeast Bering Sea shelf, and Aleutian Islands. We focus on variables in the global model projections that are relevant to the marine ecosystem, including surface and sub-surface temperatures, mixed layer depth, upper ocean stratification, and transport associated with major ocean currents. A multi-model ensemble approach is used towards the development of robust estimates of pdfs for the regions of interest. This approach permits quantification of the "structural" uncertainties associated with differences in model formulations and a means of ranking the models in terms of the magnitudes of their projected changes. The latter information represents context for studies on the effects of climate forcing on regional ecosystems and resources that consider a subset of global climate models.

## S1-P9

### Records of bleaching events in Brazilian reef communities

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The Western Atlantic Ocean reef communities underwent more mass bleaching events than any other area in the world. Monitoring such events is important to verify how the populations behave and respond to multiple stressors. Here, we present a review of the bleaching records in Brazil, which encompasses the vast majority of South Atlantic reef communities. The unofficial records date back to the early 1990's and the first paper was published only in 1998. After that, the production did not intensify until the 2010's, when >70% of the bleaching reports were published. The identification of the bleaching phenomenon was made mostly visually while *Symbiodinium* concentration was assessed in few papers. The majority of the papers presented short timeframes, although some presented 8 or even 17 years of monitoring. Most likely due to its high diversity, 90% of the events were recorded in the Northeastern region, where most of coral reef Marine Protected Areas are found. Bleaching was identified in 21 species, with *Siderastrea stellata* described as bleached in more than 50% of the papers. *Montastraea cavernosa*, addressed in 13% of the works, was the most resistant among 25 species. The majority of the papers attributed the bleaching to temperature anomalies, varying between 0.25 and 3.2 above the average. UV radiation, sedimentation, low salinity and anthropic activities were also considered impacts. Compared to other areas of the world, Brazilian reefs are still poorly monitored, with a remark lack of temporal data.

## S1-P10

### The effect of extreme cooling events on ocean ecosystems and biogeochemistry: Fisheries implications

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Volcanic and nuclear winter have similar global climate implications: penetration of light-blocking aerosols into the stratosphere result in long residence times, blocking sunlight, leading to global cooling, reduction in photosynthesis, and decreases in precipitation. Here we present preliminary results from the first study to simulate this global cooling effect in an Earth system model with enabled ocean biogeochemistry (CESM-BEC). Our first focus is on simulations of nuclear winter resulting from a Russia-US nuclear exchange, inputting 150 Tg of soot into the stratosphere. Results here are applicable to understanding the effects of large volcanic eruptions, as well as asteroid impacts, on ocean ecosystem and biogeochemical processes. Effects on global and regional fisheries production will be highlighted.

## **S2: From prediction to projection: the role of seasonal to decadal forecasts in a changing climate**

### **S2-P1**

#### **Do sun spots influence the onset of ENSO and PDO events in the Pacific Ocean?**

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The sea surface temperature (SST), anomalies (SSTA, ERSSTv4), ONI and MEI in regions El Niño 1+2 and 3.4 as well as the Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation indexes were correlated to sun spot (SS) number from cycles 19 to 24 at different lagging times (0-48 months). The highest correlation was found between 6-36 months. The SS 19-23 cycles had 9-29% direct impact on SSTA in Niño 3.4, whilst in Niño 1+2 was negligible (<1%) except for cycle 19 (40%). However, during the ascendant phases of cycles an impact of 46 to 64% (6-48 months) and 43-64% on SSTAs in Niños 3.4 and 1+2 were registered respectively. The PDOs were linearly correlated up to 77% (12 to 24 months) along the ascendants phases. The curve gradients alternated from positive to negative one after another cycle. The AMO was always inversely correlated up to 7, 17, 37% from cycles 20 to 23 respectively. Sea surface temperature is affected by SS, particularly in the ascendant phases of the researched cycles, and that is reflected in the above-mentioned indexes. The higher the slope of the ascendant phase of the cycles the higher the impact. These changes must be considered when evaluating predicting ENSO (high frequency) models as well as low frequency events as PDO and AMO.

### **S2-P2**

#### **The effect of climate change to the Chesapeake Bay Plume Dynamics**

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The Chesapeake Bay outflow plume (CBOP) is the mixing zone between the Atlantic Ocean and Chesapeake Bay, the largest and most biological diverse coastal plain estuary in North America. Using a numerical model, the simulated historical CBOP was classified into five types based on the orientation, shape, and size along with the available satellite imagery from 2003-2012. It was also found that streamflow and wind magnitude were responsible for the seasonal variability in surface plume area and thickness, respectively, and that streamflow explained most of the interannual variability in both surface plume area and thickness. Biogeochemical simulations were also conducted in order to determine the dominant environmental drivers of primary production in the plume region during these ten-year simulation, phytoplankton showed severe nitrogen limitation.

With the help of a robust climate model(s) and watershed model, a downscaling method was applied to project the possible future physical and biological CBOP structure. How the effect of climate change to the Chesapeake Bay and its plume was given, ideal (uncertainty) experiments were then performed to explore the response of the plume (water quality) signatures to ambient salinity, sea level rise, and sea temperature, as projected by climate forcing, such as CMIP5 (Coupled Model Intercomparison Project Phase 5) models.

## S2-P3

### The South Pacific Decadal Variability connections to basin-scale climate

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The decadal variability of the Pacific Ocean is often discussed in terms of dominant modes of the North Pacific, such as the Pacific Decadal Oscillation (PDO), the North Pacific Gyre Oscillation (NPGO), the North Pacific Meridional Mode (NPMM), and their links to the El Niño Southern Oscillation (ENSO). However, climate variability in the South Pacific has also been shown to play an important role in the Pacific Decadal Variability (PDV). We outline a hypothesis for Pacific decadal climate variabilities combining the dynamics in both the South and North Pacific and clarify the specific roles of different modes and their connections based on the evidences from observational data and a climate model. The PDV consists of an inter-hemispherical symmetric part and an asymmetric part. The North/South Pacific meridional modes (MMs) can influence the tropical variabilities (e.g. ENSO) independently, while ENSO teleconnections are of importance to synchronize the PDV across the south and North Pacific. We focus more on extending the framework to the southern hemisphere in this work. We investigated the important climate modes in the South Pacific and clarified the connections and dynamic processes between them. Thus, we develop a symmetry framework of the PDV between the north and South Pacific to deepen our understanding of the PDV.

## S2-P4

### A framework for combining seasonal forecasts and climate projections to aid risk management for fisheries and aquaculture

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A changing climate, in particular a warming ocean, is likely to impact marine industries in a variety of ways. For example, marine aquaculture may not be able to maintain production in their current location into the future, or area-restricted fisheries may need to follow the fish as they move. Preparation for potential climate impacts can be improved with information about the future. Such “climate-proofing” is a risk-based management strategy that can be used by industries exposed to both short-term environmental variability and long-term change. In southern Australia, where Australia’s most valuable and highest volume coastal aquaculture and many regional fisheries occur, indications of adverse climate impacts are beginning to emerge, and climate-proofing is a new coping strategy. Information about future conditions can aid industry decisions associated with climate-proofing. We introduce a decision tree to explain the potential use of climate projections and seasonal forecasts in climate-proofing these seafood operations. Long-term climate projections provide insight into the likely time in the future when current locations will no longer be suitable for growing or catching particular species. In the interim, seasonal forecasting is beneficial in helping marine industries plan ahead to reduce impacts in poor years and maximize opportunities in good years. Use of seasonal forecasting can extend the period of time in which industries can cope in a location as environmental suitability declines due to climate change. While a range of short-term forecasting approaches exist, including persistence and climatological forecasts, only dynamic model forecasts provide a viable option for managing environmental risk for marine industries in regions where climate change is reducing environmental suitability and creating novel conditions.

## S2-P5

### Lessons from the first generation of marine ecological forecast products

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Recent years have seen a rapid expansion in the ability of earth system models to describe and predict the physical state of the ocean on time-scales from seasonal (3 months) to decadal (5-10 years). With the advance of these forecasts of ocean physics, the first generation of marine ecological forecasts has started to emerge. We review the state of the art in this new field and identify the lessons that can be learned and carried forward. The majority of this first wave of products is forecasts of spatial distributions, possibly reflecting the inherent suitability of this response variable to the task of forecasting. Promising developments are also seen in forecasting fish-stock recruitment, phenology and coral-bleaching events. Moving marine ecological forecasting forward will require striking a balance between what is feasible and what is useful. We propose here a set of criteria to quickly identify “low-hanging fruit” that can potentially be predicted; however, ensuring the usefulness of forecast products also requires close collaboration with actively engaged end-users. Realising the full potential of marine ecological forecasting will require bridging the gaps between marine ecology and climatology on the one-hand, and between science and end-users on the other. Nevertheless, the successes seen thus far and the potential to develop further products suggest that the field of marine ecological forecasting can be expected to flourish in the coming years.

## S2-P6

### Exchange dynamics at Maryland Coastal Bays under the effect of climate change

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In an easily well-mixed estuary of Maryland Coastal Bays (MCBs), exchange dynamics at inlets (Ocean City Inlet and Chincoteague Inlet) between the bays and the adjacent Atlantic Ocean were investigated by applying a state of art, three-dimensional (3D) hydrodynamic model. It was found that exchange dynamics at inlets based on a 10-year (2003-2012) simulation was very sensitive to the physical forcing and climatic variability. Thus, the physical external forcing projected by Coupled Model Inter-comparison Project Phase 5 (CMIP5) with wind pattern shifts, river inflow fluctuations, sea level rise, sea temperature increase, and salinity changes in the MCBs, were used to drive this 3D hydrodynamic model. The variation between the 10-year and forthcoming-decade on exchange dynamics at the MCBs was compared to quantify the magnitude and direction of flux under the potential climate change. The statistical relationship between the flux intensity and major external forcing were established to elucidate the hiding mechanisms, which provides a comprehensive understanding of hydrodynamics of the MCBs under the effect of future climate change to initiate other potential related water quality and ecosystem studies in the MCBs in the future.

## S2-P7

### Projections of marine ecosystem change in European seas in the 21<sup>st</sup> century

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Climate change projections at regional scale are becoming more widely available, for example through the CORDEX project, but many of these are atmosphere only. Downscaled regional sea projections are less common, and projections that include marine biogeochemistry are even rarer. I will present projections for European seas for the 21<sup>st</sup> century, under Representative Concentration Pathways 4.5 and 8.5. The projections include the entire European Atlantic coast, the North Sea and the Mediterranean Sea, for the period 1960 to 2099. The model resolution is 0.1 degree (about 11 km), compared to a typical resolution in CMIP5 global climate models of 0.5 to 1 degree. The physical component of the modelling system is the well-established model POLCOMS, and the biogeochemical component is ERSEM, a relatively complex ecosystem model with multiple plankton types and separate tracking of carbon, nitrogen, phosphorus and silicon. The model was driven at the surface by a regionally-downscaled climate model, and boundary conditions were taken from the same global climate model. The outputs show the scale of change that can be anticipated and allow the identification of hotspots of change. Primary production is projected to increase in the western Mediterranean but decrease over much of the eastern Mediterranean and the North Sea. The difference between RCPs is much larger in the Mediterranean than the North Sea, for both temperature and primary production. This set of projections will be used to provide information for fisheries and aquaculture managers across Europe, and they will also be useful for marine spatial planning.

## S2-P8

### Projected sea surface temperature changes in the fishing areas of the Colombian Pacific under climate change scenarios

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Ocean warming is expected to modify abundance and distribution of marine fishery resources in the tropical marine ecosystems. To study possible effects of warming in the Colombian Pacific marine fisheries we used sea surface temperature (SST) from multi-General Circulation Models (GCM) (CNRM-CM5, HadGEM2-ES, MPI-ESM-LR y MPI-ESM-MR) ensemble from Coupled Model Inter-comparison Project, Phase 5 (CMIP5) database. We constructed statistical downscaled SST for the climatic period 1950-2095 using a combination of historical runs (1950-2005), future scenarios 2006-2035 (2020s), 2036-2065 (2050s), 2066-2095 (2080s) under different representative concentration pathways (RCP) 2.6, 4.5, 8.5. SST Climatology was calculated for the period 1979-2013 from the ORAP 5 database by the European Center for Medium-Term Meteorological Forecasting (ECMWF) to simulate present day and future SST for comparing changes in the artisanal and industrial fishing zones. Additionally, regionalization of Colombian Pacific was carried out on SST climate change using *K* means clustering analysis. The results indicate that the present day high catch artisanal and industrial fishing zones would experience an increase of 2-3°C in SST during the mid (2050s) and long term (2080s). Grouping analysis on future scenarios reveal regionalization changes with respect to present day climatology and an expansion of water masses towards the north of Colombian Pacific. These SST changes may affect current fishing zones in the Colombian Pacific by altering the (distribution and abundance) availability of current fish population and their interaction with fishing gear particularly in the artisanal high catch fishing grounds.

## S2-P9

### **A wavelet approach to time series analysis for the anchovy recruitment and climate change in the southeastern waters of Korea**

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We demonstrated anchovy recruitment variation and the effects of climate change using Multivariate ENSO Index (MEI), coastal water temperature and catch statistics for the juveniles by anchovy drag net fishery in the Korean southeastern coastal waters. Wavelet analyses allowed us to quantify both the pattern of variability in the time series and non-stationary associations between anchovy recruitment and climatic signals. Phase analyses were carried out to investigate dependency between the two signals. This analysis shows significant peaks intermittently during the occurrence of El Niño events at a scale of 8–16 months between anchovy juvenile catch and MEI with coastal water temperature at 10 m depth. Therefore MEI and coastal water temperature were considered to be yearly variation with the association of anchovy recruitment as indicator of climate and ocean environmental factors. We will discuss changes in the recruitment strength through the effect to migration and reproductive activity of adults and survival rate during early life stage in association with the ocean environment in the spawning and nursery grounds due to the climate change in the Korean coastal waters.

## S2-P10

### **Multi-annual climate predictions for fisheries: An assessment of skill of sea surface temperature forecasts for Large Marine Ecosystems**

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Sea surface temperature (SST) anomalies are both leading indicators and important drivers of marine resource variability. Fisheries managers are therefore interested in assessing if temperature over the next years to decade will be high or low relative to the 30–50 used to develop their management frameworks. Skillful multi-annual SST predictions may thus improve marine resource management decisions and ensure societal benefits. We demonstrate that the GFDL CM2.1 multi-annual prediction system could often constrain whether temperatures were likely to be cold or warm relative to a ~50-year reference period typical for well-developed fisheries datasets. Probabilistic forecasts of upper and lower sea surface temperature (SST) terciles over the next 3 or 10 years showed significant improvements in skill over the use of a 50-year climatology for most Large Marine Ecosystems (LMEs) in the North Atlantic, the western Pacific, and Indian oceans. Multi-annual prediction skill arose primarily from the predictable effects of accumulating greenhouse gases rather than low frequency climate variations. North Atlantic LMEs stood out as the only coastal regions where initialization significantly contributed to SST prediction skill at the 1 to 10 year scale.



## S2-P11

### More reliable coastal SST forecasts from the North American multimodel ensemble

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Sea surface temperature (SST) anomalies are leading indicators and important drivers of marine resource fluctuations. Previous work has shown that global climate prediction systems have significant SST anomaly prediction skill for many coastal ecosystems, despite coarse resolution. These predictions have furthermore been shown to have the potential to improve harvest controls. In this study, we assessed the potential for a multi-model ensemble to improve seasonal SST predictions for coastal ecosystems. The SST anomaly prediction skill of monthly sea surface temperature (SST) anomaly predictions across the coastal large marine ecosystems (LMEs) of the United States and Canada was assessed using simulations from the North American Multimodel Ensemble (NMME). The forecasts based on the full ensemble are generally more skillful than predictions from even the best single model. The improvement in skill is particularly noteworthy for probability forecasts that categorize SST anomalies into upper (warm) and lower (cold) terciles. The ensemble provides a better estimate of the full range of forecast values than any individual model, thereby correcting for the systematic over-confidence (under-dispersion) of predictions from an individual model. Probability forecasts, including tercile predictions from the NMME, are used frequently in seasonal forecasts for atmospheric variables and may have many uses in marine resource management.

## S2-P12

### Interannual variability of marine ecosystem in the Kuroshio Extension region

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Interannual variability of marine ecosystem in the Kuroshio Extension (KE) region is investigated using an eddy-resolving coupled physical-biological model. The model reproduces the observed interannual variability of sea surface height anomaly (SSHA) in the KE region along a zonal band of 32–34°N from 2000 to 2012. The negative SSHA is shown in 2000 to 2002, 2006 to 2010, and 2012, and the positive SSHA is shown in 2003 to 2005, and 2011. Distributions of high (low) nitrate and phytoplankton concentrations correspond to negative (positive) SSHA. Cyclonic eddies (negative SSHA) are found to detach from the KE jet near 150°E and 158°E, and propagate westward. The westward propagating cyclonic eddies lift the nutrient-rich water into the euphotic zone, and maintain high levels of phytoplankton concentration in summer to fall. When the passing of strong cyclonic eddies (strong negative SSHA), especially, in 2012, the high nitrate water is lifted close to the surface layer, and appears the high surface phytoplankton concentration. Every winter, deep convection inside the eddy entrains high levels of nutrients into the mixed layer, increasing production, resulting in high phytoplankton concentration throughout the surface mixed layer. By contrast, anticyclonic eddies (positive SSHA) depress the nutrient-rich water (maintain oligotrophic condition), and the surface phytoplankton concentration in summer remains low, in 2003 to 2005.

## S2-P13

### **Downscaling global climate projections to the Bering Sea: A rapid hybrid dynamical-statistical method to generate a large regional ensemble**

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Dynamical downscaling is a powerful technique for the exploration of regional response to global climate change, yet is costly at fine spatial and temporal scales. Statistical downscaling trained on present local conditions is computationally fast, yet can be misleading as dominant spatial patterns and processes shift through time. Here we explore a hybrid statistical scheme, trained using dynamical downscaling results, which quickly generates a large ensemble of projected futures for the Bering Sea at fine (10km) spatial scale using readily available large-scale forcing datasets from global models. Twelve projections of global climate from CMIP3/CMIP5, including multiple emission scenarios and modeling centers, were dynamically downscaled and used to derive the (spatial/cross-variable) covariance structure relating the large-scale forcing to the regional response. We employed this covariance structure to generate the regional biophysical response to a much larger ensemble of CMIP5 output, using only the large-scale forcing terms as predictors. Training and validation of the method proceeds using pairs of the downscaling runs, *i.e.* using the covariance structure of one model/scenario to replicate the results of a different model/scenario. This hybrid dynamical-statistical technique can replicate over half of the signal derived from a full dynamical downscaling, for variables such as sea surface and sea bottom temperature on the Bering Sea shelf. The hybrid method is useful for biological variables as well, although its skill varies spatially; for large crustacean zooplankton, patterns from the hybrid method are closest to those of full dynamical downscaling in the vicinity the shelf break.

## S2-P14

### **Potential predictability of mesoscale eddy activities in the western boundary current regions in an ensemble eddy-resolving OGCM**

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Given the possible importance of variability in the western boundary currents and associated eddy activities on oceanic physical states and ecosystem, it is important to understand potential predictability of mesoscale eddy activities. Inherently, eddy activities can be unpredictable as eddies are induced by oceanic internal dynamics rather than atmospheric forcing. In the Kuroshio Extension region, however, it has been suggested that some parts of mesoscale eddy activities are associated with decadal variability in the Kuroshio Extension jet that could be influenced by wind-driven Rossby wave propagation. This implies existence of some potential predictability of eddy activity in the region. In this study, to investigate potential predictability of mesoscale eddy activity, we have conducted eddy-resolving quasi-global OGCM ensemble experiments for 35 years. Based on the five ensemble members with slightly different initial conditions, potential predictability in eddy activity is shown to be increasing eastward along the Kuroshio Extension. While this suggests the potential predictability tends to low in high eddy activity region, the property is not clear in the Gulf Stream and the Agulhas Current regions.

### S3: Carbon uptake, ocean acidification, and ecosystems and human impacts

#### S3-P1

#### Seasonal and Interannual variability of partial pressure of carbon dioxide (pCO<sub>2</sub>) and air-water CO<sub>2</sub> flux pattern along the southwest Bay of Bengal-Northern Indian Ocean region

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The time series observations were conducted along southwest Bay of Bengal (SWBoB) from January 2013 to March 2017 to examine the influence of physical and biological processes on water column nutrients biogeochemistry. The total alkalinity and dissolved inorganic carbon showed the clear seasonal pattern with the minimum during post monsoon and the maximum in monsoon along with lowest pH and high pCO<sub>2</sub> level. In addition, the seasonal and interannual variability of pCO<sub>2</sub> and air-sea flux of CO<sub>2</sub> has been studied with the help of seasonally derived pCO<sub>2</sub> maps using the empirical relationships between the dependent variables of pCO<sub>2</sub> such as SST and chlorophyll. Development of seasonal pCO<sub>2</sub> algorithms using in-situ SST and chlorophyll datasets have been regressed with the pCO<sub>2</sub> using sigmaplot. Validation of remotely sensed pCO<sub>2</sub> map and calculated pCO<sub>2</sub> data showed high significant co-efficient of determination ( $R^2=0.723$ ) with the SEE of  $\pm 3.216$ , MNB (0.064) and RMSE ( $\pm 27.694 \mu\text{atm}$ ). The atmospheric pCO<sub>2</sub> level ranged between 384.624 and 395.665  $\mu\text{atm}$  from 2013 to 2017 which indicates the gradual increase of atmospheric pCO<sub>2</sub> at a rate of 0.45  $\mu\text{atm Y}^{-1}$ . The interannual CO<sub>2</sub> flux ranged between -0.45 and 1.14  $\text{mmolCm}^{-2}\text{d}^{-1}$ . Coastal waters act as net annual source of CO<sub>2</sub> to the atmosphere, the offshore and open ocean waters of the SWBoB act as a net sink of atmospheric pCO<sub>2</sub> during summer season while it serves as the strong source of CO<sub>2</sub> to the atmosphere during monsoon from 2013–2017 with the super saturation of CO<sub>2</sub>.

**Keywords:** Seasonal and Interannual, pCO<sub>2</sub>, CO<sub>2</sub> flux, Bay of Bengal and Indian Ocean

#### S3-P2

#### Temporal variation of the saturation state of carbonate in intermediate waters of western North Pacific

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Many studies have investigated the acidification of surface waters, but only few information exist for acidification state of sub-surface waters. Response of mesopelagic organisms against sub-surface acidification has also remained almost unknown. In 1997, we had investigated the saturation state of carbonate in the intermediate waters of western North Pacific, as well as the vertical distribution and morphology of *Globorotalia scitula*, a typical mesopelagic-floating foraminifer. Repeated observation was then carried out in 2016–2017, and the 20-years difference of carbonate saturation state and vertical distribution of *G. scitula* were evaluated. DIC had significantly increased in the waters above the isopycnals of  $S_q = 27.0$ , and the saturation horizon of aragonite had shoaled from the isopycnals of  $S_q = 26.9$  in 1997 to that of  $S_q = 26.8$  in 2016–2017. In the waters between  $S_q = 27.1$  to 27.4, on the other hand, slight decrease of DIC from 1997 to 2016–2017 were observed as well as significant increase of water temperature and salinity. As this result, the saturation horizon of calcite had deepened from the isopycnals of  $S_q = 27.2$  in 1997 to that of  $S_q = 27.3$  in 2016–2017. Vertical maximum of *G. scitula* population had moved from the density range of  $S_q = 27.1 - 27.2$  in 1997 to that of  $S_q = 27.2 - 27.3$  in 2016–2017. This may indicate that *G. scitula* had changed its main habitat along with the temporal shift of the saturation horizon of calcite.

### S3-P3

#### Potential impacts of ocean acidification on the southern Benguela food web

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Climate projections indicated that South African marine environments are forecast to experience an increase in sea surface temperature of ~ 3°C and a decrease of ~ 0.3 pH units by the end of the century. Ocean acidification is expected to modify the growth and calcification rates of marine calcifiers and behavioural traits of fish. Furthermore, sensitivity to acidification is intensified when taxa are simultaneously exposed to increased seawater temperature. The warming and acidification forecast for South Africa can therefore be expected to have detrimental effects on a number of species and potentially on the ecosystem as a whole. This study aims to determine the impacts of ocean acidification on the functioning of the southern Benguela upwelling system. The Atlantis end-to-end ecosystem model, forced by climate projections from NEMO-MEDUSA 2.0, was used in the study. Since very few studies have evaluated the effect of ocean acidification on species in South Africa, a meta-analysis of the pH sensitivities of local taxa and taxa present in other upwelling systems is used to inform model simulations. This is combined with a sensitivity analysis to address uncertainties in the estimates of pH sensitivity. We developed scenarios in which the mortality of phytoplankton, zooplankton, squid and fish groups were affected by ocean acidification. Our study describes progress made to date in identifying the ecosystem impacts of ocean acidification in the southern Benguela.

### S3-P4

#### Elevated CO<sub>2</sub> effects on shell dissolution rates of two estuarine benthic foraminifera

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Oceans have continuously absorbed anthropogenic CO<sub>2</sub> from the atmosphere. The absorbed CO<sub>2</sub> has changed seawater carbonate chemistry by altering pH, carbonate ion concentrations (CO<sub>3</sub><sup>2-</sup>) and calcium carbonate saturation states. Lowered seawater pH may influence both deposition and dissolution rates of mineralized skeletons in many marine organisms such as Foraminifera. The present study examined the effect of ocean acidification on post-mortem dissolution rates of two species of benthic foraminifera, *Elphidium williamsoni* and *Haynesina germanica*. Sediment samples were collected from Eden estuary N.E Scotland in late July 2017. 100 dead foraminiferal specimens of each species were randomly selected and continuously exposed for 6 weeks to seawater with known equivalent atmospheric concentration of CO<sub>2</sub> (400, 800 and >2000 μatm pCO<sub>2</sub>) into three reservoir tanks, respectively. Thus, the three selected pH levels of 8.1, 7.7 and 7.3 represented the range of pH predicted for future scenarios in a high CO<sub>2</sub> world. The greatest test weight loss and test dissolution rate were observed for both species at pH level of 7.3. The present study showed that elevated CO<sub>2</sub> levels increased the test dissolution rates in two dominant benthic foraminiferal species. Increasing atmospheric CO<sub>2</sub> concentrations and the impacts of Ocean Acidification in coastal waters are likely to drive a significant change in estuarine calcium carbonate levels and the balance of calcification in these environments in the near future.

**Keywords:** Ocean acidification, *Elphidium williamsoni*, *Haynesina germanica*, dissolution rate, Eden estuary

### S3-P5

#### The effect of ocean acidification on *Ulva lactuca* in relation to the associated bacteria metabolic interactions – A lab study

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Alexandria is a coastal city that lies on the Mediterranean seashore where the coastal waters are the sink of daily CO<sub>2</sub> pollution emitted from cars and electric utilities. The CO<sub>2</sub> gas reacts with seawater to form carbonic acid and then to different carbon salts. This shift of seawater chemistry causes an ocean acidification over time. In these habitats, algae and the associated microbes not only undergo the stress of such acidification but also they are living under a variation of four seasons. In this respect, our thoughts went to explore the capability of an algal cell to live in and adapt to these ambient conditions. *Ulva* sp., which grows year around on rock and in the shallow waters, is chosen as an investigational organism. The alga was collected and maintained at the lab in enriched seawater with different pH grades corresponding to the atmospheric CO<sub>2</sub> concentration (pCO<sub>2</sub>). The experimental design represents the pH values relative to the current pCO<sub>2</sub> of 400 ppm (pH approximately 8.1) and the predicted future conditions of acidified seawater corresponding to projected mid-century and late-century pCO<sub>2</sub> levels of 560 ppm (pH: approximately 7.85) and 1140 ppm (pH: approximately 7.60), respectively. Using the analytical techniques, the scenarios will go to address the following objectives: the performance of the algal growth; the compositional analysis of the associated bacterial assemblage; and the biologically active metabolites involved in those possible ecological interactions, as a result of the acidification stress.

### S3-P6

#### Effect of ocean acidification on Antarctic marine organisms – A meta-analysis

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Southern Ocean waters are amongst the most vulnerable in the world to ocean acidification and organisms inhabiting these waters are likely to experience damaging effects as a consequence of changes in carbonate chemistry. A meta-analysis was performed to examine the effects of ocean acidification on Antarctic marine biota occupying waters south of 60°S. This showed that ocean acidification negatively affected pelagic (e.g. phytoplankton, krill, pteropods, fish) and benthic organisms (e.g. urchins, bivalves, crustaceans). The sensitivity of phytoplankton to ocean acidification differ among species, with many studies showing that it alters community composition, favouring smaller cells. The few studies of other pelagic and benthic organisms suggest that fertilization and shell formation is often reduced, and certain developmental stages are sensitive to ocean acidification. Our analysis indicates that Southern Ocean marine organisms are likely to be susceptible to ocean acidification, which may cause shifts in community composition, with implications for ecosystem services in the future. However there is still much uncertainty with poor spatial coverage, few studies that encompass multiple trophic levels, and levels of resilience and the potential for organisms to acclimate and/or adapt to the changing conditions are largely unknown.

### S3-P7

#### **A marine carbon model coupled with an operational ocean model product for ocean acidification studies in the North Western Pacific**

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Ocean acidification causes serious damages to marine ecosystems such as coral reefs in the subtropical region and species or groups of organisms in the polar region. Damages due to increasing the ocean acidity are further predicted to affect broader areas and bring about great risks of marine organisms. We recently have developed a marine carbon model coupled with an operational ocean model product (JCOPE), aiming at investigating ongoing ocean acidification processes in the North Western Pacific, focusing on their associated physical-biogeochemical processes and social risks. The latest version of the model successfully reproduced reasonable chlorophyll-a, nutrients and pH values, after a lot of improvements including initial conditions of carbon parameters and multiple parameter optimization. Simulated seasonal variability, however, shows some problems yet, especially for chlorophyll-a variation in the subarctic region. We will solve these issues in future and will provide the information on the present status of the carbon cycle in the marginal/coastal sea areas around Japan.

### S3-P8

#### **Ocean acidification alters morphology of all otolith types in 3D, delays settlement in Clark's anemonefish (*Amphiprion clarkii*)**

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Ocean acidification, the ongoing decline of surface ocean pH and  $[\text{CO}_3^{2-}]$  due to absorption of surplus atmospheric  $\text{CO}_2$ , has far-reaching consequences for marine biota, especially calcifiers. Among these are teleost fishes, which internally calcify otoliths, critical elements of the inner ear and vestibular system. There is evidence in the literature that ocean acidification increases otolith size and alters shape, perhaps impacting otic mechanics and thus sensory perception. However, existing analyses of otolith responses to ocean acidification are limited to 2-dimensional morphometrics and shape analysis. Here, we reared larval Clark's anemonefish, *Amphiprion clarkii* (Bennett, 1830), in various seawater pH treatments analogous to future ocean scenarios in a 3x-replicated experimental design. Upon settlement, we removed all six otoliths from each individual fish and analyzed them for treatment effects on morphometrics including area, perimeter, and circularity, as well as four mineralogy metrics evaluated by visual examination of scanning electron micrographs: lateral development, percent visible crystals, crystal habit, and crystal polymorph. Additionally, we analyzed treatment effects on fish mortality, settlement timing, and somatic growth. Our results reveal myriad ocean acidification impacts on all otolith types as well as fish settlement and somatic growth. These impacts may have consequences for otolith function, and in turn teleost fitness, in the near-future ocean.

### S3-P9

## Influence of human activities on C:N ratio of riverine organic matter along the Pearl River in South China

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Transport of organic matter (OM) from lands to oceans by river is a significant geochemical process in the global carbon cycle. The conventional view is that the terrestrial OM C:N ratio from a river into an estuary is higher than marine OM C:N ratio and therefore, terrestrial OM is considered to be the carbon source in the estuary and adjacent coastal waters. However, we hypothesize that the input of OM by human activities changes OM C:N ratio. We tested the hypothesis through investigate OM C:N from upstream to the estuary along the Pearl River. The results showed that organic carbon increased from less than 100 $\mu$ M upstream to about 200 $\mu$ M in the Pearl River estuary, and OM C:N was higher about 12:1 in the upstream section when the Pearl River is relatively pristine and decreased downstream when the water was enriched with nitrogen, reaching OM C:N ratio about 4.26~6.28 in the Pearl River estuary. We also found riverine DOC had a strong positive correlation with  $\text{NO}_3^-$ , but DOM C:N ratio had a strong negative correlation with  $\text{NO}_3^-$ .  $\text{NO}_3^-$  concentration could reflect the degree of human impacts. This further proved OM CN ratio decline is result from human OM input. In summary, our research demonstrate that human activities increase the Pearl River organic carbon output but decrease OM C:N ratio. And the Pearl River output OM C:N ratio is lower than 6.7. These OM have become carbon sink instead of carbon source at the estuary and coastal ocean.

### S3-P10

## Multi-decadal temperature, oxygen and pH trends in the upper layer of the Western Mediterranean Sea

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The global climate change induces a warming and an acidification of ocean's surface waters (as reported by many authors). In several oceanic areas, deoxygenation due to water stratification has also been mentioned. The Mediterranean Sea is affected by global change as well, and its turnover is fast as compared to global ocean. Taking advantage of historical data availability, we analyze the trends in temperature, oxygen and pH levels over a few decades on the western Mediterranean basin. Preliminary results show that, depending on the season, the observed increase of temperature is not the same: in summer and fall, the trends are not clear; in winter and spring a regular increase is observed for 5 decades. This leads to a decrease of the temperature seasonal amplitude and thus, to strong ecological consequences favoring the invasion of tropical species in Mediterranean waters. The upper waters of the Western Mediterranean (0-200 m) show on average an increase of oxygen concentrations. This increase may be due to mesoscale features such as meanders and anticyclonic eddies. In surface waters, when pH observations are available, they show a strong decrease of 0.2 pH unit over 30 years which is much larger than what is observed for the global ocean: The Mediterranean Sea, exhibiting a high alkalinity, has a strong potential of anthropogenic carbon absorption.

### S3-P11

#### **Examining the integrated effects of ocean acidification and warming on shell development, structural integrity, and incidence of epizootic shell disease in the juvenile American lobster, *Homarus americanus***

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The American lobster fishery is a significant component of the coastal New England economy and community. Native lobster populations are currently experiencing rapid warming and acidification due to climate change. We are examining these combined effects on shell development and incidence of disease in juvenile American lobsters, an inherently stressful life stage due to the energetic demands on rapid growth and associated molting. Preliminary data from our experiments suggest that juveniles grown under low pH/high temperature conditions show differential gene expression compared with the control treatment. Genes coding for calcification proteins (CASP-2 and CP14), cuticle growth proteins, and chitinase were all upregulated under the multi-stressor conditions. Shell mineralogy was similarly affected with significantly less weight percent of calcium detected through energy dispersive x-ray spectroscopy (EDS) in lobsters grown in the low pH/high temperature treatment, impacting smaller juveniles more severely. Evidence of shell disease lesions and bacterial colonies was detected in some specimens using scanning electron microscopy (SEM); we expect our analyses to reveal some disease lesions across all treatments, but severity and spread to be greater in the multi-stressor treatment with associated evidence of decreased mineral density and structural integrity. The results of this intensive study can enhance our understanding of shell development in the juvenile American lobster: how it precipitates and distributes mineral polymorphs within the cuticle layers, the role that these minerals have in protecting against bacterial and disease intrusion, and how these components together may be affected by pH and temperature stressors associated with climate change.

### S3-P12

#### **The economic impacts of ocean acidification on shellfish fisheries and aquaculture in the United Kingdom**

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Ocean acidification may pose a major threat to commercial fisheries, especially those for calcifying shellfish species. This study was undertaken to estimate the potential economic costs resulting from ocean acidification on UK wild capture and aquaculture shellfish production. Applying the net present value (NPV) and partial equilibrium (PE) models, we estimate both direct and economy-wide economic losses of shellfish production by 2100. Estimates using the NPV method show that the direct potential losses due to reduced shellfish production range from 14% to 28% of fishery NPV. This equates to annual economic losses of between £3 and £6 billion of the UK's GDP in 2013, for medium and high emission scenarios. Results using the PE model showed the total loss to the UK economy from shellfish production and consumption ranging from £23-£88 million. The results from both the direct valuation and predicted estimate for the economic losses on shellfish harvest indicate that there are regional variations due to different patterns of shellfish wild-capture and aquaculture, and the exploitation of species with differing sensitivities to ocean acidification. These results suggest that the potential economic losses vary depending on the chosen valuation method. This analysis is also partial as it did not include a wider group of species in early-life-stages or predator-prey effects. Nevertheless, findings show that the economic losses to the UK and its devolved administrations due to ocean acidification could be substantial. We conclude that addressing ocean acidification with the aim of preserving commercially valuable shellfish resources will require regional, national or international solutions using a combined approach to reduce atmospheric CO<sub>2</sub> emissions and shift in focus to exploit species that are less vulnerable to ocean acidification.

**Keywords:** Crustaceans, Marine climate change, Risk assessment, Molluscs, Economic costs, Shellfish production



### S3-P13

#### **Morphology and habitat depth of planktic foraminifer in intermediate waters of western North Pacific: Implications of relationship to carbonate saturation states**

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The ocean acidification is certainly observed and progressing at the global ocean, but its knowledge is still limited only in the surface water. In particular, there is no information of biological impact on deep-dwelling organisms. Here we focused on deep-dwelling planktic foraminifer *Globorotalia scitula* (Brady) and tried to detect the progress of ocean acidification in intermediate water and biological impact during this 20 years. Planktic foraminifers were collected by the MOCNESS from isopycnals of  $S_q = 26.4-27.4$  (ca. 0~1,000 m water depth). The saturation horizon of calcite had deepened from the isopycnals of  $S_q = 27.2$  to that of  $S_q = 27.3$  during this two decades. The distribution of *G. scitula* in the water column was from sub-surface to deeper water, and its maximum abundance was around  $S_q = 27.2-27.3$  (ca. 500-700 m) in 2016-2017. In contrast, that of the previous study in 1997 was  $S_q = 27.1-27.2$  (ca. 400-500 m). Interestingly, the water depth of maximum occurrences of *G. scitula* was almost correspond with the carbonate saturation horizon of calcite ( $\Omega_{cal}=1.0$ ) in both periods. Furthermore, shell density of *G. scitula* measured by Micro X-ray CT showed no remarkable differences between each water depths. It suggests that planktic foraminiferal depth habitat can shift flexibly with carbonate saturation horizon, and thereby its calcification is less disturbed by surrounding carbonate chemistry.

### S3-P14

#### **Tackling diverse marine climate-change challenges: From nuclear-based techniques to policy**

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Ocean acidification and warming occur at global scales and, particularly in the case of temperature, have already caused notable shifts in coastal and marine ecosystems. The IAEA Environment Laboratories in Monaco have developed and now implement nuclear science-based techniques to better understand the function and health of these changing ecosystems. This is accomplished using controlled aquaria where key environmental parameters, such as ocean hypercapnia, acidification, dissolved oxygen, salinity and temperature can be finely regulated and controlled. Experimental results from these microcosms clearly indicate that the movement of a broad suite of contaminants into commercially relevant marine organisms is affected systematically by shifts in these master parameters. Such information is useful to Member States as they develop guidelines and trainings to assess marine climate change impacts, particularly with respect to ecosystem resources and services, and associated seafood safety/security programmes. This talk will present new findings in OA research being conducted at the IAEA Laboratories in Monaco within the context of raising awareness for IAEA Member States and addressing the UN Sustainable Development Goal (SDG) 14.3 (ocean acidification).

### S3-P15

#### Ocean acidification impact on the grooved carpet shell clam (*Ruditapes decussatus*)

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The grooved carpet shell clam (*Ruditapes decussatus*) is one of the most popular and profitable mollusk of lagoonal and coastal sites in the Mediterranean. Specimens were incubated in CO<sub>2</sub> enriched seawater for the aim of studying the impact of different levels of acidification on this calcifying organism. Four different CO<sub>2</sub> concentrations (420ppm (ambient control), 550 ppm, 750 ppm and 1050 ppm) were chosen following the projected atmospheric CO<sub>2</sub> concentrations by IPCC scenarios for the year 2100. The studied biological parameters showed a significant decrease in the shell lengths as pCO<sub>2</sub> concentration increased with a maximum average decrease (-0.09) recorded at 1050ppm compared with the control group that had average  $\Delta$  shell length changes after the incubation of (-0.04). On the subject of total weight of clams the  $\Delta$  total weight was the highest (-0.10) recorded in both 550 and 1050 ppm. Moreover, the clams studied at 550ppm showed the lowest condition index ( $11.40 \pm 1.49$ ) and highest mortality rate of 8%. The study of physiological response showed increase in metabolic rate and ammonia excretion in both 550 ppm group and the control 420 ppm group. Gradual elevation in clearance rate beginning with control 420 ppm group till extremely high pCO<sub>2</sub> groups. Furthermore, the Scanning Electron microscope results highlighted a trend towards obvious superficially physical sensitivity to acidification. These results indicated that, the projected increase in pCO<sub>2</sub> in the next century exerts an additional stress on the health of *R. decussatus* and its economic value.

**Keywords:** ocean acidification, pCO<sub>2</sub>, *Ruditapes decussatus*, biological parameters, physiological response, mortality.

### S3-P16

#### Effects of high CO<sub>2</sub> and temperature on the physiology, behavior and development of American lobster larvae: Comparing subpopulations across New England's steep thermal gradient

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Anthropogenic carbon released into the atmosphere has led to rapid, concurrent increases in temperature and acidity across the world's oceans, most prominently in the northern latitudes. The geographic range of the iconic American lobster (*Homarus americanus*) spans one of the steepest thermal gradients on the planet, and is exhibiting a poleward range shift in the warming Northwest Atlantic. Understanding the interactive effects of ocean warming and acidification on this species' most vulnerable early life stages is important to predict its response to climate change on a stage-specific and population level. Our study compares the responses of lobster larvae to the joint effects of elevated pCO<sub>2</sub> and temperature across three sub-populations spanning New England's north-south temperature gradient (Rhode Island, Midcoast Maine, and Eastern Maine, USA). Using a full factorial experimental design, we subjected planktonic larval and post-larval stages to different combinations of ambient, end-century projected, and extreme pCO<sub>2</sub> concentrations (400 ppm, 750 ppm, 1200 ppm), and ambient and projected end-century temperatures (16°C and 19°C). Data will be presented showing changes in growth, oxygen consumption, carbon-to-nitrogen ratio, swimming speed, feeding behavior, and gene expression to different combinations of these interactive environmental stressors. Results suggest that temperature will have a larger influence over parameters of development and behavior than pCO<sub>2</sub>.

### S3-P17

#### **Effects of ocean acidification on snow crab larvae: Carryover effects from embryogenesis and oogenesis reduce direct effects on larval survival**

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Ocean acidification, a decrease in ocean pH with increasing anthropogenic CO<sub>2</sub> concentrations, is expected to affect many marine animals. We determined the effects of ocean acidification on the economically important snow crab, *Chionoecetes opilio*. By holding females in treatment pH for two brooding cycles (two years) and using the resulting larvae, we assessed carryover effects from oogenesis and embryogenesis. Ovigerous females were held at three pHs: ~8.1 (Ambient), 7.8, and 7.5. When larvae hatched from each treatment, they were exposed to similar pH treatments in a fully crossed experimental design. Starvation-survival, morphology, condition, and calcium/magnesium content were assessed for larvae in both years. In the first year, starvation-survival of larvae reared at ambient pH but hatched from embryos reared at low pH was reduced; however, the negative effect was eliminated when the larvae were reared at reduced pH. In the second year, there was no direct effect of either embryo or larval pH treatment, but larvae reared as embryos at reduced pH survived longer if reared at reduced pH. Larvae hatched from embryos held at pH 7.5 had lower calcium content right after hatching, but the effect was transitory in the second year. There was no effect of larval treatment on calcium content or effect of embryo or larval treatment on magnesium content in either year. These results suggest both that larvae are highly tolerant of low pH, and that embryos are not only able to acclimate to low pH but that this effect carries over to the larval stage.

### S3-P18

#### **Ocean acidification does not affect embryo development, hatch success, or adult calcification in Bering Sea snow crab, *Chionoecetes opilio***

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Ocean acidification, a decrease in ocean pH due to absorption of anthropogenic CO<sub>2</sub>, has variable effects on different species. To examine the effects of decreased pH on snow crab (*Chionoecetes opilio*), a commercial species in Alaska, we reared ovigerous females in one of three treatments: ambient pH (~8.1), pH 7.8, and pH 7.5, through 2 annual reproductive cycles. Morphometric changes during development and hatching success were measured for embryos both years and calcification was measured for the adult females at the end of the 2-year experiment. Embryos and larvae analyzed in year one were from oocytes developed, fertilized, and extruded in situ, whereas embryos and larvae in year two were from oocytes developed, fertilized, and extruded under acidified conditions in the laboratory. Embryo morphology during development was unaffected by pH during both years. Embryo mortality and hatching success did not differ with treatment in either year. Percent calcium in adult females' carapaces did not differ among treatments at the end of the experiment. The results from this two-year study suggest that snow crabs are well adapted to projected ocean pH levels within the next 2 centuries, although other life-history stages still need to be examined for sensitivity. These results contrast sharply with those of the southern Tanner crab, *Chionoecetes bairdi*, in which embryo development and hatching success were strongly reduced under acidified conditions in similar experiments. Future work will examine the physiological responses in both species to elucidate what mechanisms drive the differential outcomes in these two sympatric congeneric species.

## S3-P19

**Ocean acidification can release top down control on early life stages of a marine habitat-forming species**Fiona **Tomas**<sup>1,2</sup>, Robert Sean Fitzpatrick<sup>1,3</sup>, Clea van de Ven<sup>4</sup>, Josep Alos<sup>1</sup>, and Iris E. Hendriks<sup>1,2</sup><sup>1</sup> Instituto Mediterráneo de Estudios Avanzados (UIB-CSIC), Esporles, Spain. E-mail: fiona@imedea.uib-csic.es<sup>2</sup> Oregon State University, Corvallis, OR, USA<sup>3</sup> Duke University, Durham, NC, USA<sup>4</sup> University of Amsterdam, Amsterdam, The Netherlands

While ocean acidification is generally viewed as a major threat to marine biodiversity, primary producers may become “winners” as they benefit from increased availability of CO<sub>2</sub>, the primary substrate for photosynthesis. Considering effects at the species level however may be too simplistic. In fact, plant-herbivore interactions are remarkably intense in marine environments and can have important cascading ecological effects in communities based on foundation species. One such group is seagrasses, which create key coastal ecosystems that provide numerous ecosystem services but which are declining worldwide. Seagrass seedlings are crucial for enabling long distance dispersal and for providing the genetic variation necessary for future adaptation to environmental changes, and thus understanding the effects of climate change on these early life stages is a pressing issue. We examined the effects of ocean acidification on the interaction between seedlings of the endemic seagrass *Posidonia oceanica* and their main herbivore, the sea urchin *Paracentrotus lividus* through a mesocosm approach. Our results indicate that *P. oceanica* may benefit from OA via a decrease in top-down control. Feeding behavior of herbivores was affected by ocean acidification, with urchins preferring seedlings grown under ambient rather than acidified conditions, and being overall were less active consumers (i.e. with lower consumption rates) under ocean acidification. Our results have important implications for functioning of seagrass ecosystems and highlight the need of incorporating species interactions when trying to understand and predict the effects of climate change in coastal ecosystems.

## S3-P20

**Ocean acidification and warming induce mortality and shell loss in *Nassarius reticulatus* (L.) veligers jeopardizing the species survival**Isabel B. Oliveira<sup>1</sup>, Filipe Laranjeiro<sup>1</sup>, Joana G. Fonseca<sup>2</sup>, Daniela B. Freitas<sup>2</sup>, Rui J. M. Rocha<sup>1</sup>, Mariana Hinzmann<sup>3</sup>, Jorge Machado<sup>3</sup>, James Weston<sup>4</sup>, Carlos **Barroso**<sup>1</sup> and Susana Galante-Oliveira<sup>1</sup><sup>1</sup> Biology Department & CESAM, University of Aveiro, Aveiro, Portugal. E-mail: cmiguez@ua.pt<sup>2</sup> Biology Department, University of Aveiro, Aveiro, Portugal<sup>3</sup> Laboratory of Applied Physiology, Department of Aquatic Production, ICBAS, University of Porto, Porto, Portugal<sup>4</sup> New York University Abu Dhabi Core Technology Platform, Abu Dhabi, United Arab Emirates

Marine calcifiers are especially prone to be negatively impacted by ocean acidification and warming. To assess the combined effects of the temperature rise and acidification (pH decrease by pCO<sub>2</sub> increase) on *Nassarius reticulatus* veligers –common gastropod in the NE Atlantic – a factorial experimental design of three pCO<sub>2</sub> conditions at four temperatures was applied. The pH control resembles the present-day pCO<sub>2</sub> at the specimens’ collection site – Ria de Aveiro, NW Portugal – resulting in pH≈8.1, plus two scenarios following the IPCC projections: short-term (≈750µatm by 2100, targeting pH 7.8) and long-term (≈1500µatm, targeting pH 7.5). Two temperature controls were considered: mean SST at the Ria de Aveiro mouth – 16°C – and the mean registered during the species’ spawning season – 18°C – plus two projected scenarios of +0.2°C/decade (20 and 22°C, respectively). Nearly-hatched veligers were obtained by caesarean of mature egg capsules and exposed, in duplicate, for 14 days. Mortality was inspected after 2 (D<sub>2</sub>), 8 (D<sub>8</sub>) and 14 (D<sub>14</sub>) days of exposure, and shell loss quantified at D<sub>14</sub>. Mortality was significantly affected by the interaction between both stressors, augmenting with acidification and warming throughout the experiment. Shell loss was only observed under the most acidic condition (pH 7.5), effect intensified by warming: 33.3% at 16°C, 52.6% at 18°C and 66.7% at 20°C, while no survivors were observed at 22°C. There is a synergic effect of acidification and warming in *N. reticulatus* veligers’ mortality, a dramatic consequence if associated with shell damage and loss in the case long-term projections become effective, threatening this species survival.

### S3-P21

## Effects of sea-ice and biogeochemical processes and storms on under-ice water $f\text{CO}_2$ from winter to spring in the high Arctic Ocean: Implications for sea-air $\text{CO}_2$ fluxes

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The ice cover in the Arctic Ocean has decreased during the last decades, manifested in particular as an extensive transition from thicker multiyear ice to thinner first-year ice. As the summer sea-ice cover is decreasing, larger areas with open water will be exposed to the atmosphere. This will have implications for the carbonate chemistry and sea-air carbon dioxide ( $\text{CO}_2$ ) exchange. We present measurements of  $\text{CO}_2$  fugacity ( $f\text{CO}_2$ ) and estimates of the effects biogeochemical processes in the surface water under Arctic sea ice, driving the sea-air  $\text{CO}_2$  fluxes. The data was obtained from January to June 2015 during the Norwegian young sea ICE (N-ICE2015) expedition, where the ship drifted with four different ice floes and covered the deep Nansen Basin, the slopes north of Svalbard, and the Yermak Plateau. This unique winter-to-spring data set includes the first winter-time under-ice water  $f\text{CO}_2$  observations in this region. The observed under-ice  $f\text{CO}_2$  ranged between 315  $\mu\text{atm}$  in winter and 153  $\mu\text{atm}$  in spring, hence was undersaturated relative to the atmospheric  $f\text{CO}_2$ . Although the sea ice partly prevented direct  $\text{CO}_2$  exchange between ocean and atmosphere, frequently occurring leads and breakup of the ice sheet promoted sea-air  $\text{CO}_2$  fluxes. The  $\text{CO}_2$  sink varied between 0.3 and 86  $\text{mmol C m}^{-2} \text{d}^{-1}$ , depending strongly on the open-water fractions (OW) and storm events. The maximum sea-air  $\text{CO}_2$  fluxes occurred during storm events in February and June. In winter, the main drivers of the change in under-ice water  $f\text{CO}_2$  were dissolution of  $\text{CaCO}_3$  (ikaite) and vertical mixing. In June, in addition to these processes, primary production and sea-air  $\text{CO}_2$  fluxes were important. The cumulative loss due to  $\text{CaCO}_3$  dissolution of 0.7  $\text{mol C m}^{-2}$  in the upper 10 m played a major role in sustaining the undersaturation of  $f\text{CO}_2$  during the entire study. The relative effects of the total  $f\text{CO}_2$  change due to  $\text{CaCO}_3$  dissolution was 38%, primary production 26%, vertical mixing 16%, sea-air  $\text{CO}_2$  fluxes 16%, and temperature and salinity insignificant.

## **S4: Deoxygenation in Global Ocean and Coastal Waters in Relation to Climate Change**

### **S4-P1**

#### **Community structure and physiological responses of zooplankton in the upwelling system of the Eastern South Pacific: Effect of the oxygen minimum zone**

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Intensification and expansion of oxygen minimum zones (OMZ) in the world ocean may have important ecological and biogeochemical consequences affecting the population and community dynamic of zooplankton. Changes in species composition, as well as in physiological responses to oxygenation can be assessed by studying the tolerance and adaptation of key species inhabiting the upwelling zone subjected to the OMZ. The analyses of zooplankton samples and experiments on ecophysiological responses: egg and faecal pellets production, hatching success and naupliar and copepodid development rate and naupliar survival of the dominant euphausiid, *Euphausia mucronata*, and dominant copepods, *Acartia tonsa*, *Calanus chilensis* and *Centropages brachiatus*, interacting with the OMZ in the eastern South Pacific, under hypoxia conditions, were performed. From field and experimental data, the seasonal variations in taxa composition and physiological responses were recorded. Both community structure and physiology of zooplankton can be strongly altered by stressful conditions due to hypoxia. These effects can result in changes of species dominance and population dynamics, with implications for the pelagic food web in the eastern boundary upwelling systems in face of a future scenario of expansion and intensification of its OMZ.

### **S4-P2**

#### **The role of the SPM absorbed phosphorus in oxygen consumption in the Pearl River estuary**

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The Pearl River estuary is a subtropical P limited estuary which connects the Pearl River to the South China Sea. The water quality and ecosystem of the estuary vary seasonally and spatially due to the variation of physical and biological processes caused by monsoon and river discharge change. We conducted a two-day cruise along the estuary once a month during 2015-2016 to investigate the role of SPM absorbed phosphate in dissolved oxygen consumption. In the wet season, high river discharge brought higher DIP ( $\sim 1.5 \mu\text{mol/L}$ ) which caused higher chl-*a* (reach  $\sim 25 \mu\text{g/L}$ ) and lower DO (below  $4 \text{mg/L}$ ) than that in the dry season. Absorbed phosphate in the wet season (reach  $\sim 2 \mu\text{mol/L}$ ) as a P supplement would release to the ambient waters and increase chl-*a* and DO at the middle estuary. The increased organism consumed the DO during decomposition downstream of the estuary especially at the bottom. In the dry season, although P adsorption was lower than that in the wet season, the utilization of absorbed phosphate by phytoplankton increased the chl-*a* and the DO concentration. The decomposition after the growth resulted in the chl-*a* and the DO concentration declined and released higher DOP to the water, that might support a new phytoplankton growth and DO consumption. Suspended particulate matters and their capacity of absorbed P might play an important role in the circulation of P retention and hypoxia occurrence under the global warming.

**S4-P3**

**The IOC-UNESCO Global Ocean Oxygen Network (GO<sub>2</sub>NE): Collaboration across disciplines and national boundaries to promote research and awareness of ocean oxygen decline**

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Declining oxygen in coastal and oceanic waters is one of the major manifestations of global change. This 'ocean deoxygenation' can affect productivity, species distributions, biogeochemical cycles, and, ultimately, human welfare. GO<sub>2</sub>NE -The Global Ocean Oxygen Network - was established by IOC in 2016 to facilitate interactions and communication among researchers studying various aspects of deoxygenation, to develop capacity building activities, and to help inform policymakers on the issue of declining ocean oxygen. Historically, eutrophication-induced hypoxia in coastal ecosystems and naturally occurring oceanic low oxygen zones have been treated as distinct phenomena. Both forms of deoxygenation are, however, predicted to worsen with increasing temperatures and human population growth, and affect physiological processes, animal movement and nutrient cycles. During the past 2 years, GO<sub>2</sub>NE members have organized a side event at the UN Ocean Conference, established a Western Pacific oxygen network, started a website highlighting new research and events related to oxygen decline, collaborated with other research networks, planned a summer school in China, and published a review paper on the topic. Next September, Kiel will host what we plan to be the first of regular, biennial research conferences focusing on oxygen decline in the open ocean and coastal waters. Our goal for this poster is inform the larger research community of the activities of the core working group and to seek input for future activities that could help engage the broader research community.

## **S5: Climate change impacts on high latitude systems on multiple scales in space and time**

### **S5-P1**

#### **Evaluation of iron sources and sea ice variability in the Ross Sea and implications for the phytoplankton seasonal cycle**

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Large blooms of the haptophyte *Phaeocystis antarctica* and diatoms in the Ross Sea are supported by dissolved iron supplied by sea ice melt and vertical entrainment of deeper iron-rich waters. The relative contribution of these iron sources and the effect of sea ice variability on the development and maintenance of these blooms is evaluated using a one-dimensional numerical model that includes the complexities of the *P. antarctica* life cycle, diatom growth, iron and irradiance controls, and the taxon's response to the changes in these variables. Simulations indicate that sea ice melt accounts for 20% of total iron inputs during low light conditions in late November-early December, which stimulates a *P. antarctica* bloom. As this iron source is depleted, advective inputs of dissolved iron (60% of total iron inputs) maintain the *P. antarctica* bloom through early January and support development of a diatom bloom in early to mid-January. Uptake by *P. antarctica* (solitary cells and colonies) accounts for the largest sink in the simulated dissolved iron budget, with uptake by diatoms being the second largest sink. Remineralization of detritus by bacterial processes is the largest biological source of dissolved iron. Sensitivity studies show that surface input of dissolved iron from sea ice melt, a transient event early in the growing season, sets up the phytoplankton temporal progression and bloom magnitude, suggesting that the productivity of the Ross Sea system is vulnerable to changes in the extent and magnitude of sea ice.

### **S5-P2**

#### **Climate change impacts on Arctic marine resource productivity: Interlinking ecological, economic and institutional scenarios**

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Arctic marine resources overlap is increasing (in space and time) as climate change narrows the availability of appropriate habitat ranges for existing species to survive, and new species enter and compete. This challenges the management of both commercial and ecosystem-valued species. An invasive crab species (snow crab) offers a platform to explore adaptive conservation challenges for Arctic countries facing dynamic and spatial changes in new (crab) and existing (benthic and commercial) resource productivity. Shifting supply and increasing demand (esp. Asia) add economic uncertainty to the ecological changes. Ongoing sovereign and international policy interests matter, as they evolve in ongoing legal cases. The crabs differ in their uncertainty, biology, economic, climatic and political factors. We exploit these differences using quantitative and qualitative data in a bio-economic framework with scenarios that span time and space dimensions. The crab invasions in the Barents Sea region serve as a building block for broader pan Arctic conservation issues as climate change shifts species ranges, productivity, and economic opportunities. Optimal decision-making regarding commercial species such as crab in ecosystems must incorporate how strategic institutional shifts, occurring in response to the economic incentives, asymmetrically affect local and global stakeholders in addition to standard concerns over ecological and economic damages amidst climate change.



## S5-P3

### Environmental variability and chum salmon production at the northwestern Pacific Ocean

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Chum salmon, *Oncorhynchus keta*, distribute widely in the North Pacific Ocean, and about 76% of chum salmon were caught from Russian, Japanese, and Korean waters of the northwestern Pacific Ocean during the last 20 years. Although it has been speculated that the recent increase of salmon production was contributed not only by the enhancement program of chum salmon but also by the favorable ocean conditions since the early 1990s, the ecological processes for determining the yield of salmon were not clearly delineated. To investigate the relationship between yield and controlling factors for ocean survival of chum salmon, time-series of climate indices, seawater temperature, and prey availability in the northwestern Pacific including Korean waters were analyzed using some statistical tools. The results of cross-correlation function (CCF) analysis and cumulative sum (CuSum) of anomalies indicated that there were significant environmental changes in the North Pacific during the last century, and each regional stock of chum salmon responded upon the Pacific Decadal Oscillation (PDO) differently: for Russian stock, the correlations between PDO index and catch were significantly negative with time-lag of 0 and 1 years; for Japanese stock, significantly positive with time-lag of 0-2 years; and for Korean stock, positive but no significant correlation. The results of statistical analyses with Korean chum salmon also revealed that the coastal seawater temperature over 14°C and the return rate of spawning adult to natal river had a negatively significant correlation.

## S5-P4

### Climate effects on phytoplankton blooms in the Barents Sea

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Variations in physical conditions caused by climate change are likely to have large influence on biological conditions of marine organisms including phytoplankton. We here investigated associations between satellite derived chlorophyll data from the Barents Sea and abiotic factors such as sea surface temperature, sea ice concentration, mixed-layer depth and wind speed. We particularly investigated how increased open water area and duration of open water season, through the measured physical factors, associate with phytoplankton phenology. In the seasonally ice-covered region, preliminary statistical analysis results show that the phytoplankton peak on average occurs approximately two weeks after the sea ice concentration falls below 50% in the spring. However, the association is nonlinear: earlier sea ice retreat before the mid May is not associated with earlier timing of the phytoplankton bloom, suggesting that other factors than sea ice prevent a bloom before this time. Earlier sea ice retreat is nonetheless associated with a larger bloom, possibly due to more mixing of nutrients into surface waters. Results further suggest that the relative importance of the different physical factors for phytoplankton dynamics differ among Barents Sea regions.

## S5-P5

### **Ecosystem outcomes of climate change and fishing impacts on krill, *Euphausia superba*, in the Scotia Sea, and their implications for management in a changing ocean**

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Climate change is a threat to marine ecosystems and the services they provide, and outcomes may necessitate re-assessment of trade-offs among these services. In the Scotia Sea, Antarctic krill, *Euphausia superba*, are critical forage for an array of charismatic predators important for ecotourism and of wide conservation concern, and support a significant international fishery. The crucial role of krill for wildlife and people denotes the potential for strong trade-offs among related ecosystem services, especially as climate change impacts the region. We used a minimally realistic ecosystem model to examine the potential of ocean warming and fishing to affect Antarctic krill and consequently their predators in the Scotia Sea, and assessed how results could inform future international policy. We found ocean warming increased projected risks for krill and some predator populations, especially penguins. Results further indicated fishing could exacerbate risks, possibly in nonlinear ways, and that curtailing fishing had some potential to offset combined consequences. Critically, results differed by spatial scale, suggesting aggregation at regional levels could mask local declines, and varied across location and species group, indicating some predator populations may be more vulnerable than others. These findings signify the importance of targeting protection measures at appropriate spatial scales and identifying vulnerable populations. They also denote the potential for management approaches, such as marine protected areas and feedback management strategies, to avoid aggravating risks associated with rising ocean temperatures and aid in balancing tradeoffs among marine ecosystem services in an uncertain future.

## S5-P6 (CANCELLED)

### **Dynamic changes in two eastern Bering Sea groundfish stocks and relative impacts of temperature-dependent growth and their consequences for fisheries management**

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Current groundfish management strategies have had limited testing relative to projected environmental changes and expected population responses. Methods to project climate change and habitat variability for the eastern Bering Sea have improved through the development of advanced physical models. Projected output from such models can characterize future habitat patterns (e.g., the extent of the “cold pool”) relative to environmental changes. Results from dendrochronology analyses of Bering Sea yellowfin sole otoliths indicate a favorable year-effect on growth in warming conditions. Contrasting these historical observed changes in growth and recruitment relative to the environment can be applied to projected environmental conditions to evaluate consequences on population dynamics. Here we contrast how temperature affects flatfish and pollock growth increments and the extent these changes affect reproductive capacity and common fishery reference points. An evaluation suggests some alternative control rules that highlight climate-readiness.

**S5-P7**

**Potential changes in feeding behaviors and parasites of Antarctic fish on the East Ongul Island and King George Island, Antarctica**

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The feeding habits of the Antarctic fish *Pseudotrematomus bernacchii* (Previous name: *Trematomus bernacchii*) under the fast ice around Japanese Syowa Station and Chinese Great Wall Station were investigated during the summers between 2004 and 2016. In addition, Antarctic fish parasites were also monitored. The results showed that feeding behaviors of fish had been changed over the past years. Amphipods and krill were the major preys. However, there was a significant difference in the proportions of larger invertebrates such as squids, octopus and other crustaceans found in the fish stomachs between 2009 and 2016. Moreover, the percentage of amphipods and krill in fish stomachs declined over the 10-year period in all fish size classes. From the fish collections, the results showed that parasites of Antarctic fish both ecto- and endoparasites were also increased over the past years. Several factors including sea ice melting, habitat and environmental changes may have influenced the pattern of feeding behavior and the occurrence of parasites.

## S6: The deep ocean under climate change

### S6-P1

#### Diversity and distribution of hyperiid amphipods between Caldera – Isla de Pascua. Chile

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Hyperiid amphipods are exclusively marine and pelagic crustaceans that are distributed from the surface to abyssal depths. This group is considered the third in abundance after copepods and euphausiids, and they are important as indicators of large-scale processes, as well as in the transfer of energy in trophic webs of temperate zones. In the South Eastern Pacific they have been scarcely studied, and on Chilean waters the works are limited to coastal areas and surface waters (0-600m). The objective of this study was to contribute to the knowledge of the diversity and distribution of hyperiids in the Chilean deep ocean through a cross shelf environmental gradient. Eighteen zooplankton samples were collected during CIMAR 21 “oceanic island” cruise performed in October 2015. Oblique tows 0-1000 m were carried out with a tucker trawl net. Fifty five species were found (all from the infraorder Physosomata). The greatest species richness (22) was recorded in a single station located in the coastal transition zone and greatest abundance (Geometric Mean 12,643 ind./1000m<sup>3</sup>) was found in a nearby station in the same area. *Hyperioides longipes*, *Eupronoe minuta* and *Primno brevidens* were the most frequent and abundant species along the transect. Analysis of similarity of the community produced four clusters (Simprof p<0.05). A significant association between the community matrix and the environmental matrix was also found. Several species are now new records for this unexplored region of the South Pacific, in particular in the deep water ecosystem.

### S6-P2

#### Fluid and adaptive networks of fixed and mobile robotic platforms for the monitoring of deep-sea ecosystems

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Geophysical cycles in light intensity, photoperiod and internal tides impose a strict synchronization of species behavior through natural selection. As a result, massive populational displacements occur across pelagic and continental margin environments, directly affecting our perception of biodiversity and ecosystem functioning. To comply with the capacity of monitoring of biological indicators as proxy of ecosystem functioning the development new methodologies for sampling the composition of communities in relation to species' rhythmic activity and its environmental control is of pivotal relevance. In this scenario, different activities are being executed within the framework of the EU MarTERA ERA-Net project ARIM (Autonomous robotic sea-floor infrastructure for benthopelagic monitoring). In order to increase spatial coverage and allow for strategic and adaptive changes in monitoring, fixed cabled observatories, autonomous underwater vehicles (AUVs) and benthic robots (crawlers) will be used for a time-coordinated monitoring via platform communication. Networks of fixed and mobile video cameras will deliver fluctuations in counted individuals (as proxy of a populations' rhythms) to be linked with the surrounding habitat conditionings (*i.e.* via a concomitant acquisition of different oceanographic, chemical, and geological data). This multi-parametric monitoring is a challenge to be overcome, in order to have standardized protocols for the acquisition and automation of data processing regarding species composition (*i.e.* richness), relative abundances (*i.e.* evenness), as well as food web structure. Obtained data are of relevance since could be extended as reference for impact monitoring in industrial sectors.

## **S7: Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change**

### **S7-P1**

#### **Climate-driven latitudinal shift in fishing ground of jumbo flying squid (*Dosidicus gigas*) in the Southeast Pacific Ocean off Peru**

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The jumbo flying squid *Dosidicus gigas* is a pelagic squid species extensively distributed in the Eastern Pacific Ocean with climate related geographical variability. An analysis was carried out to evaluate impacts of climatic and oceanographic variability on spatial distribution of *D. gigas* in the Southeast Pacific Ocean off Peru. Logbook data of the 2006–2013 Chinese squid-jigging fishery were used to determine latitudinal gravity centres (LATG) of fishing ground of *D. gigas* in relation to sea surface temperature (SST), Chlorophyll-*a* (Chl-*a*) concentration and sea surface height (SSH), coupled with the SST anomaly (SSTA) in the Niño 1+2 region. Results indicated that the SSTA in the Niño 1+2 region played crucial influences on SST, Chl-*a* and SSH on the fishing ground of *D. gigas*. The LATG of *D. gigas* exhibited seasonal and interannual variability with closely associations with SST, Chl-*a*, and SSH. Significantly positive relationships were found between monthly LATG and the average latitude of the most favourable contour lines of SST, Chl-*a*, and SSH for *D. gigas*, with time lags at 0, 7, and 0 month, respectively. The spatial pattern of LATG largely responded to climate-induced oceanographic variability on the squid fishing ground: the Niño 1+2 SSTA became warm, the most favourable SST and SSH contour lines for *D. gigas* would move southward, resulting in a southward movement of the LATG; however, the Niño 1+2 SSTA shifted into cold episodes, the most favourable SST and SSH contour lines for *D. gigas* would shift northward, leading to a northward shift of the LATG. Our findings suggested that the SSTA in the Niño 1+2 region coupled with the most favourable contour lines of SST and SSH were the major drivers regulating the latitudinal movement of fishing ground of *D. gigas* in the Southeast Pacific Ocean off Peruvian waters.

### **S7-P2**

#### **Trophic amplification and attenuation of bottom-up perturbation on marine ecosystem in the Northeast Pacific under climate change**

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Recently, the Subarctic Pacific has experienced unprecedented sea surface warming, which may be analogous to future warming under climate change. It is thus important to understand how ecosystem services such as fish and fisheries production are likely to respond to such environmental perturbations. Warming and other associated changes in ocean conditions affect primary producers and consumers in the oceans through changes in physiology, biogeography and trophic interactions. Climate change may thus trigger nonlinear responses at the ecosystem level, with possible amplification of environmental perturbations at upper trophic level organisms that are important to fisheries. To test this hypothesis, we developed an end-to-end trophodynamic model of a coastal marine ecosystem in the Northeast Pacific (West Coast of Vancouver Island) that represented the trophic linkages between all components from nutrients to top-predators. This model couples a physical model with a biogeochemical model (NEMURO) and a trophodynamic model (Ecopath with Ecosim approach), thus allowing a two-way feedback between all components. We applied this model to simulate environmental perturbation scenarios to quantify the relationship between changes in primary production and fish production in order to elucidate the possibility and intensity of trophic amplification under climate change. We further evaluated the mechanism of trophic amplification with a focus on the effects of temperature on trophic transfer efficiencies and the implications for the strength of trophic cascade. Findings from this study help improve the understanding of climate change impacts on species and ecosystem production and their implications for fisheries.

### S7-P3

## The impact of the El Niño 2015-16 on the zooplankton community in Chilean Eastern Boundary Upwelling System

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Time series observations in the upwelling zone off northern and central/southern Chile allowed us to assess changes in zooplankton biomass and community structure during 2014 and 2016, coinciding with the onset and development of the strong 2015-16 El Niño event. The physical and chemical manifestation of this warm event was weaker than expected in the upwelling zone off Chile and it was characterized by a slight deepening of the thermocline and oxycline at northern and central/southern Chile and sea surface temperatures anomalies ranging 0.5-1.0°C. Zooplankton biomass and abundance did not show significant changes during the warm event, although they maintained a negative trend being observed through the last 10 years associated with increasing upwelling intensity. The analysis of zooplankton composition, mainly focused on copepod species, suggested that significant changes in the community structure are taking place as a response to increased upwelling and cooling down of the water column. Uncommon species in the upwelling zone are becoming abundant and species richness is being incremented. All these changes do not seem linked to the El Niño 2015-16 effects, but they may represent responses to a longer time-scale process occurring in the eastern South Pacific region related to inter-decadal variability or climate change.

### S7-P4

## Global hotspots of synchronous marine populations

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Synchronous population dynamics among marine populations have intrigued scientists for decades and can indicate strong environmental forcing or common predators. Commercially important fisheries that display synchronous patterns are of concern because simultaneous population crashes would likely have negative consequences for coastal fishing communities. Here, we test for the presence of synchronous patterns among marine fish and invertebrate fisheries globally, then examine the underlying mechanisms that may drive these synchronous patterns. We used wavelet analyses, a method suitable for non-stationary data that can identify both time-specific and frequency-specific synchrony patterns. These wavelet methods were used on annually-resolved Food and Agriculture Organization (FAO) fisheries catch data and on large-scale climate data. The FAO catch data consisted of 1703 populations in 16 FAO regions, with 887 distinct species across 250 families, over the period 1950 to 2014. Results show a high degree of synchrony within particular FAO regions, particularly the California Current Large Marine Ecosystem (CCLME). In this region, a majority of the 100 species across 50 families displayed synchronous fisheries catch. Synchrony was strongest at periods of less than 5-years from the mid-1960s to mid-1980s, then strongest at periods of 8 to 10-years from the 1970s to 2000s. These periods correspond to El Niño Southern Oscillation patterns and the North Atlantic Oscillation in winter, respectively. Our results suggest that climate variability drives strong synchrony among marine fisheries both globally and in the CCLME.

## S7-P5

**What controls the variability of CO<sub>2</sub> fluxes in Eastern Boundary Upwelling Systems?**Riley Brady<sup>1</sup>, Nicole **Lovenduski**<sup>1</sup>, Michael Alexander<sup>2</sup>, Michael Jacox<sup>3</sup> and Nicolas Gruber<sup>4</sup><sup>1</sup> Department of Atmospheric and Oceanic Sciences and Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO, USA. E-mail: riley.brady@colorado.edu<sup>2</sup> NOAA/Earth System Research Laboratory, Boulder, CO, USA<sup>3</sup> University of California, Santa Cruz, CA and NOAA/SWFSC, Monterey, CA, USA<sup>4</sup> Environmental Physics, ETH Zurich, Switzerland

Eastern Boundary Upwelling Systems (EBUS) are mediated by alongshore, equatorward winds that force cold, corrosive, and nutrient-enriched waters to the surface. These regions are productive biologically, compensating for the effect of upwelling on pCO<sub>2</sub>. This leads to a variable mosaic of air-sea CO<sub>2</sub> fluxes (F<sub>CO<sub>2</sub></sub>). Thus, variability in F<sub>CO<sub>2</sub></sub> in EBUS provides a constraint on the magnitude of the ocean carbon sink. This variability also dictates when we might expect the anthropogenic signal of ocean acidification to become emergent in each system. In this study, we diagnose the physical and biological mechanisms that control historical (1920-2015) F<sub>CO<sub>2</sub></sub> in the four major EBUS (California, Humboldt, Canary, and Benguela Currents). We utilize biogeochemical output from the CESM Large Ensemble, a global coupled climate model ensemble that is forced under historical and RCP8.5 radiative forcing. Differences between simulations can be attributed entirely to internal climate variability, as simulations are generated by introducing round-off perturbations to the initial atmospheric temperature. This experimental setup provides us with 34 independent and unique representations of the natural climate system, allowing us to robustly assess variability in F<sub>CO<sub>2</sub></sub>. We find that F<sub>CO<sub>2</sub></sub> in the Humboldt and Canary Currents is driven primarily by variability in ocean circulation and biology, rather than by variability in CO<sub>2</sub> solubility. The California Current is unique, as it exhibits a spatial dipole in its F<sub>CO<sub>2</sub></sub> sensitivity. We find that offshore and poleward coastal areas respond more to changes in CO<sub>2</sub> solubility, while equatorward coastal regions are most sensitive to variability in ocean circulation. A better understanding of the sensitivity of F<sub>CO<sub>2</sub></sub> in each system might lead to some short-term predictive skill in the ocean-atmosphere carbon cycle. For example, our understanding of the remote forcing and teleconnections associated with ENSO could allow us to anticipate the anomalous air-sea exchange of CO<sub>2</sub> in the major EBUS.

## S7-P6

**Mechanisms associated to the global warming-induced SST pattern in the South Eastern Pacific in the CESM-LE**Carlos **Conejero**<sup>1</sup>, Boris Dewitte<sup>1,2,3,4</sup>, Marcel Ramos<sup>2,3,4</sup> and Véronique Garçon<sup>1</sup><sup>1</sup> Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Toulouse, France. E-mail: cconejerogarcia@gmail.com<sup>2</sup> Centro de Estudios Avanzado en Zonas Áridas (CEAZA), Coquimbo, Chile<sup>3</sup> Departamento de Biología, Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile<sup>4</sup> Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile

Climate change projections indicate that the mid-latitude Eastern Boundary Current systems have been warming less than the tropical regions. The underlying mechanisms remain unclear. Here we investigate the processes associated to the mean climate change pattern in the South Eastern Pacific (SEP) based on the Community Earth System Model Large Ensemble (CESM-LE). The SST trend in the simulations for which the radiative forcing levels yield 8.5 Wm<sup>-2</sup> by 2100 (RCP8.5 scenario) consists in a tongue of minimum warming rate (~0.2°C/decade) off Central Chile that extends up to 130°W, while the rate of warming is twice as large in the eastern equatorial Pacific. A heat budget of the mixed layer is carried out which shows that such a pattern can be understood in terms of the expansion of the Hadley cell producing an increase in the subtropical gyre, and subsequent cooling due to latent heat off the coast of Central Chile and North of 20°S. While this is compensated by positive advection (warming trend) near the coast, zonal advection consists in a cooling trend off shore south of 20°S. The analysis indicates that the change in the oceanic circulation induced by the change in the winds through Ekman dynamics can explain to a large extent the trend pattern of horizontal advection. The change in the characteristics of the coastal jet off Central Chile and its impact on the coastal upwelling are also discussed.

## S7-P7

### Modelling biogeochemical trends in the Peruvian Upwelling System: Remote vs local forcing

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The Peruvian Upwelling System (PUS) is one of the most important coastal upwelling system in the world ocean because it presents an intense Oxygen Minimum Zone (OMZ) and high productivity, which supports an important fishery activity. Between the eighties and the early 2000's a sea surface temperature (SST) coastal cooling, oxycline shoaling and nearshore surface chlorophyll increase have been evidenced from observational data. In the present work we used the physical-biogeochemical coupled ROMS-PISCES model to investigate the physical and biogeochemical processes driving the biogeochemical trends from 1979 to 2008. Numerical experiments were made to investigate the influence of the remote (*e.g.* equatorial currents) and local forcing (*e.g.* upwelling favorable wind) on these trends. Our model was able to reproduce the oxycline shoaling and productivity increase. The model also estimated a deoxygenation ( $-4 \mu\text{mol.kg}^{-1}.\text{dec}^{-1}$ ) between 20-100 m depth, associated with the oxycline shoaling ( $8 \text{ m.decade}^{-1}$ ). The increase of productivity ( $+0.4 \text{ mg Chl.m}^{-3}.\text{dec}^{-1}$ ) was significant in the Northern-Central part off Peru ( $6^{\circ}\text{S}-10^{\circ}\text{S}$ ). The analysis of phytoplankton growth limiting factors obtained from the model indicated that the productivity increase was due to a reduction of nutrient limitation caused by the nutricline shoaling, while no change in light limitation was observed. Sensitivity experiments demonstrated that the remote forcing drives the oxycline shoaling and the productivity increase in the PUS, due to more frequent Central Pacific El Niño (Modoki) events related to upwelling Kelvin waves, which are associated to the shoaling of the coastal thermocline.

**Keywords:** Peruvian Upwelling System, ROMS-PISCES model, trend, OMZ, productivity

## S7-P8

### Effect of climate change on upwelling-favorable winds in the Peruvian Upwelling System

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The regional impact of the global climate change on upwelling-favorable winds in the Peruvian Upwelling System remains unclear. Previous studies suggest that coastal winds could be increased due to the enhancement of the cross-shore pressure gradient induced by an increase of the land-sea temperature difference. On the other hand, recent studies based on statistical and dynamic modeling suggest that the coastal winds could be weakened in relation to the increase of precipitation and convection off the north coast of Peru and to the poleward displacement of the South Pacific Anticyclone. The limitations of these model-based regional projections are the models relatively low spatial resolution ( $\sim 50-100 \text{ km}$ ) and the use of a single global model for the downscaling. This work presents coastal wind future projections based on results from a high resolution dynamical downscaling using the WRF regional atmospheric model. The model is applied using three nested domains with 105, 21 and 7 km resolution and up to 60 vertical levels. It is forced by the multi-model ensemble mean of a set of IPCC-CMIP5 simulations. We performed a control simulation in the period 1994-2003 forced by the NCEP2 reanalysis, and a climate change simulation where anomalies coming from the CMIP5 multi-model ensemble for the RCP8.5 scenario (period 2086-2095) are added to the NCEP2 lateral boundary conditions. Both the control and climate change simulations include a strong El Niño event, which allows to evaluate the response of the coastal winds to El Niño variability in a climate change context.



## **S8: Understanding the impact of Abrupt Ocean Warming and Continental Scale Connections on marine productivity and food security via Western Boundary Currents**

### **S8-P1**

#### **Potential impacts of climate change on physical processes and primary productivity in the Brazilian ocean warming hotspot**

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Recent studies in climate change have identified oceanic regions whose surface waters are warming up to three times faster than the global mean of the oceans over the past 50 years, called ocean warming hotspots. One of these hotspots is located in adjacent waters to the Brazilian coast that is influenced by the Brazil Current (BC). They have been showing a behavior that is projected for the global oceans under conditions of future emissions of greenhouse gases and, as a result, these regions are considered as “natural laboratories” allowing to observe the impacts of warming in advance, including those on ocean productivity. Thus this work aims to understand the physical, dynamic, and biogeochemical interactions and their effect on the BC primary productivity in the present climate and to determine the potential impact of climate changes on these interactions and on the spatiotemporal variability of associated variables and processes. To characterize the variability of physical and dynamic (temperature, salinity, and velocity), biogeochemical (nitrate, phosphate, and silicate), and primary productivity (net primary production, and chlorophyll) properties and the relationship between them in a present and future climate the results of the historical experiment (validated with satellite data) and the RCP4.5 scenario simulated by the HadGEM2-ES model will be used. Through the analysis, it will be possible to characterize the patterns of this warming hotspot and to quantify changes in stratification and circulation, as well as the implication of these on nutrient supply and primary productivity in the occurrence of future climate changes.

### **S8-P2**

#### **Effects of environmental variations on the abundance of western winter-spring cohort of *Ommastrephes bartramii* in the Northwest Pacific Ocean**

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During 1995-2011, annual production of winter-spring cohort of *Ommastrephes bartramii* for Chinese squid-jigging fishery has greatly fluctuated, which is closely related to the environmental conditions on the spawning and fishing grounds. To better understand how squid recruitment and abundance were influenced by ocean environmental conditions, biological and physical environmental variables including sea surface temperature (SST), SST anomaly (SSTA), chlorophyll-*a* (Chl-*a*) concentration and the Kuroshio Current were examined during years with the highest (1999), intermediate (2005), and lowest (2009) catches. Catch per unit effort (CPUE) of the squid-jigging vessels was used as an indicator of squid abundance. The results indicated that high SST and Chl-*a* concentration on the spawning ground in 1999 resulted in favorable incubation and feeding conditions for squid recruitment. Whereas the suitable spawning zone (SSZ) in 2009 shifted southward and coincided with low SST and Chl-*a* concentration, resulting in a reduction in the squid recruitment. The small difference of SSZ area in the three years suggested the SSZ provided limited influences on the variability in squid recruitment. Furthermore, high squid abundance in 1999 and 2005 was associated with warm SSTA on the fishing ground. While the cool SSTA on the fishing ground in 2009 contributed to adverse habitat for the squid, leading to extremely low abundance. It was inferred that strengthened intensity of the Kuroshio force generally yielded favorable environmental conditions for *O. bartramii*. Future research are suggested to focus on the fundamental research on the early life stage of *O. bartramii* and mechanism of how the ocean-climate variability affects the squid abundance and spatial distribution by coupling physical model with squid biological process to explore transport path and abundance distribution.

## S8-P3

### Assessing the Northwest Atlantic 30-year climate change using 3-D visualization

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To assess the Northwest Atlantic sea water temperature and salinity changes, we used high-resolution six decadal climatologies built on 1-, 0.25- and 0.1-degree spatial grids generated based on in situ observations held in the World Ocean Database published in 2013. We examined the difference between two 30-year climates (1985-2012 minus 1955-1984). It was demonstrated that the warming within the Northwest Atlantic is inhomogeneous, with most of the warming occurring southeast of the Gulf Stream while a sustained cooling occurred in the western and central parts of the subpolar gyre. It was also shown that the position of the Gulf Stream northern wall remains stable during all six decades without noticeable meridional fluctuation of the Gulf Stream core position on decadal time scale. We have constructed 3-D diagrams showing 30-year differences of seawater temperature and salinity to visualize spatial structure of the climate shift in this important region.

## S8-P4

### Atmospheric signature of the Agulhas Current

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The Agulhas Current is warmer than the surrounding ocean, leading to high sensible and latent heat fluxes, marine boundary layer modification and moisture convergence. How this western boundary current affects the South Africa rainfall is poorly understood? Here, using state of the art satellite, climate reanalysis datasets, and a regional climate model, we investigate the impact of the Agulhas Current on low-level atmospheric circulation and precipitation around South Africa. For the first time, we show that a narrow band of precipitation is confined above the core of the Agulhas Current and along the East Coast of South Africa. This narrow rain band is collocated with surface wind convergence, warm sea surface temperature (SST) and the minimum of sea level pressure (SLP). These results suggest that the Agulhas Current enhances convection and associated precipitation and that the pressure adjustment mechanism is at the origin of the phenomenon. WRF model simulations confirm that the surface convergence over the Agulhas Current is enhanced by the warm SST of its core. We estimate that around 40% of the convective rainfall along the eastern coast of South Africa is generated by the Agulhas Current.

## **S9: Drifting into the Anthropocene: How will pelagic marine ecosystems be affected and what are the biogeochemical and lower trophic consequences**

### **S9-P1**

#### **International efforts in plankton and ecosystems time series research**

Todd **O'Brien**, on behalf of the IGMETS, WGZE, WGPME, and TrendsPO working groups.

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In 2001, the ICES Working Group on Zooplankton Ecology (WGZE) produced its first trans-North Atlantic time-series analysis of zooplankton, using 10 participating sites. In 2004, the SCOR Global Comparisons and Zooplankton Time Series working group (WG125) expanded this effort globally. Over the next four years, WGZE and WG125 together assembled a collection of over 150 zooplankton time series. Based on the success of these groups, parallel efforts started in the phytoplankton community, first with the ICES Working Group on Phytoplankton and Microbial Ecology (WGPME), then globally with the SCOR Global Patterns of Phytoplankton Dynamics in Coastal Ecosystems working group (WG137), which later became the IOC-UNESCO working group to investigate Climate Change and Global Trends of Phytoplankton in the Ocean (TrendsPO). In 2014, the IOC-UNESCO International Group for Marine Ecological Time Series (IGMETS) brought together these plankton groups, along with biogeochemical researchers, and established a broader marine ecological time series community of over 350 time series from 38 countries.

This poster summarizes the progress, findings, publications, and future work of these international, collaborative efforts, and invites time-series-holding Symposium participants to get involved. Searchable interfaces, information and links to these various time-series working groups, and the time series themselves, are available online through the IGMETS Metabase (<http://igmets.net/metabase>).

### **S9-P2**

#### **Effects of typhoon events on chlorophyll and carbon fixation in different regions of the East China Sea**

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Typhoons play an important role in the regulation of phytoplankton biomass and carbon fixation in the ocean. Data from the moderate-resolution imaging spectroradiometer (MODIS) on 35 typhoon events during 2002–2011 are analyzed to examine the effects of typhoon events on variations in sea surface temperature (SST), chlorophyll-*a* (Chl-*a*), and depth-integrated primary productivity (IPP) in the East China Sea (ECS). For all 35 typhoon cases, the average SST drops by 0.1°C in the typhoon influenced regions, and the maximal decrease is 2.2°C. During the same period, average Chl-*a* increases by 0.1 mg m<sup>-3</sup>, with the maximal increase reaching up to 1 mg m<sup>-3</sup>, and average IPP increases by 32.9 mg C m<sup>-2</sup>·d<sup>-1</sup>, with the largest increase being 221 mg C m<sup>-2</sup>·d<sup>-1</sup>. The IPP are significantly correlated with SST and Chl-*a* data, and the correlations become stronger after typhoon passage. Effects of the typhoon events on SST, Chl-*a*, and IPP manifest differently in the three key sea areas, namely, the coastal water (depths <50 m), continental shelf (depths 50–200 m), and open sea (depths >200 m) regions in the ECS. Specifically, stronger responses are observed in shallow water than in deeper depths. Overall, our results reveal that there is a close coupling between Chl-*a*, SST, and IPP in shallow areas and that typhoon events can have strong effects on carbon fixation in coastal regions, and typhoon events will produce even more important effects on the carbon cycle than before, under the circumstance of global warming.

## S9-P3

**Shifting pattern of phytoplankton species response to climate change and eutrophication in Gyeonggi Bay**Roksana **Jahan**<sup>1,2</sup>, Taeyoon Song<sup>3</sup> and Joong Ki Choi<sup>3</sup><sup>1</sup> Environmental Quality, Atmospheric Science and Climate Change Research Group, Ton Duc Thang University, Ho Chi Minh City, Vietnam. E-mail: roksana.jahan@tdt.edu.vn<sup>2</sup> Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam<sup>3</sup> Department of Oceanography, INHA University, Nam-gu, Incheon 402-751, Korea

In Gyeonggi Bay, climatic regime shift detected in 1989, followed by the ecological shift in 2000, which had significant impact on phytoplankton phenological change from single (spring) to bimodal peak (winter-summer). To test the hypothesize “shifting pattern of phytoplankton dominant species can be brought by synergistic effect of climate change and eutrophication” we conducted a detailed case study on phytoplankton species during 1992-1997 and 2001-2010, nutrients and climatic factors during 1992-2010. Climatic factors caused the fluctuation of nutrient availability that shifted pattern of dominant species during winter. For instance, tychopelagic diatom (*i.e. Paralia sulcata*) was dominant during 1990s winter, whereas *Thalassiosira nordenskioldii* during 2000s winter. The mechanism for the former case was that higher wind speeds maintained resuspension processes that brought nutrient-rich higher saline water to the surface. In contrast, the mechanism for the latter case was temperature associated with climatic factors (*i.e.* reduced wind speed and suspended solids) that had negative impact of *P. sulcata* and, consequently, maintain proper temperature and nutrients for *T. nordenskioldii*. The synergistic effect of warming associated with lower wind speed and huge precipitation during 2000s summer could have caused stratification that enhanced higher abundance of nanoflagellates. *Prorocentrum minimum* were dominant during 1990s summer due to eutrophication. Our study showed that climate change and eutrophication shifted the phenology and pattern of phytoplankton species.

## S9-P4

**Temperature influences pennate diatom and flagellates in Gyeonggi Bay**Roksana **Jahan**<sup>1,2</sup>, Mohammad Saeed Ullah<sup>3</sup> and Joong Ki Choi<sup>3</sup><sup>1</sup> Environmental Quality, Atmospheric Science and Climate Change Research Group, Ton Duc Thang, University, Ho Chi Minh City, Vietnam. E-mail: roksana.jahan@tdt.edu.vn<sup>2</sup> Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam<sup>3</sup> Department of Oceanography, INHA University, Nam-gu, Incheon, Korea

To test the hypothesis “temperature influences on pennate diatom and flagellates”, >52 phytoplankton species were collected from Gyeonggi Bay during October 2008-May 2009. Centric diatom significantly negatively related with temperature and preferred from 5.13 to 9.99°C. The underlying mechanism was that lower temperature associated with higher wind speed and tidal cycles during winter could enhanced resuspension processes and brought higher salinity (>31.81), suspended solids (<160 mg l<sup>-1</sup>) and nutrients in surface that were sufficient for centric diatom abundances (*i.e. Thalassiosira nordenskioldii*, *Chaetoceros* spp., etc.). Abundances of some centric diatom (*i.e. Eucampia zodiacus*, *Ditylum brightwellii*, etc.) were lower when SS exceeded 160 mg l<sup>-1</sup> due to light limitation. In contrast, pennate diatom and flagellate significantly positively related with temperature (15.34-20.7°C). The mechanism was that higher temperature associated with precipitation introduced stratification, lower salinity (<25) and suspended solids (<100 mg l<sup>-1</sup>) in surface, that enhanced light penetration, and higher nutrient loading through river discharge is also regular phenomena during summer; all these factors influence pennate diatom (*i.e. Navicula* sp., *Pseudonitzschia* sp., *Thalassiothrix* sp., etc.) and dinoflagellates (*i.e. Prorocentrum micans*, *Protoperidinium* sp. *Pseudonitzschia* sp.). Moreover, physiological structure of small-size diatom and flagellates (higher surface: area ratios) would support higher abundance at warming condition. Some species (*i.e. Paralia sulcata*, *Skeletonema costatum*, *Coscinodiscus* sp., etc.) could tolerate wide range of temperature and salinity. This study suggests that ocean warming could shift the phytoplankton community structure from diatom to flagellates in Gyeonggi Bay.

## S9-P5

### Assessing the legacy effects of climate change on the world's oceans utilizing reversibility scenarios

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The oceans are key regulators of the Earth's climate and marine ecosystems provide highly-valued socio-economic services. Anthropogenic climate change has already impacted the ocean and earth system models project continued alteration under future carbon emissions scenarios. This has spurred consideration of diverse climate change mitigation strategies. Very little is known, however, about what would happen to our ocean under mitigation. The utility of idealized greenhouse gas reversibility scenarios to investigate processes driving responses under mitigation was demonstrated in a study by John *et al.* (2015), which showed that legacy effects of climate change continue even as mitigation is implemented under a reversal of the RCP8.5 scenario. Results will be presented from a multi-model reversibility intercomparison to assess the range of uncertainty in ocean responses in an idealized RCP8.5 mitigation projection. Additionally, results from an idealized ramp-up/ramp-down 1% to 4×CO<sub>2</sub> simulation will be assessed to contrast and compare to the ramp-up/ramp-down RCP8.5 multi-model suite. Preliminary results show that broad-scale global temporal, spatial, and subsurface responses are robust across the multi-model suite for variables such as temperature. Regional responses such as oxygen in upwelling regions may differ across models however, and vastly different responses may be obtained (*e.g.* in net primary production), likely due to model structural differences. These initial results indicate that additional reversibility studies are needed to better understand and quantify climate, ocean, and ecosystem responses under mitigation.

## S9-P6

### Development of a global ocean biogeochemistry observing system

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The global oceans are rapidly changing, so our method of monitoring them must also change to keep up. Oceanic biogeochemical properties, such as oxygen and pH, have profound impacts on fisheries and marine resources, but traditional observing techniques are limited in spatial and temporal coverage. This also limits the ability of resource managers to adequately manage these global commons. A new type of profiling float, called Biogeochemical Argo (BGC Argo), has been developed and it allows for unprecedented numbers of biogeochemical observations from the global oceans. Similar to the Core Argo program, BGC Argo measures temperature and salinity, in addition to pH, nitrate, oxygen, chlorophyll, suspended particles and irradiance. These 6 additional sensors have been developed, tested and improved by the BGC Argo community through a variety of international efforts to improve the understanding of global ocean biogeochemistry. Early results from BGC Argo floats have been promising and include quantification of undocumented winter-time CO<sub>2</sub> flux from the Southern Ocean and validation of satellite color algorithms for chlorophyll. As the Core Argo program has had substantial impact on the physical oceanography community, it is likely that BGC Argo will also greatly improve our understanding of the ocean's biogeochemical processes. With these improvements, scientists and policymakers can work together to improve management of fisheries, forecasting of dead zones and mitigation of otherwise harmful impacts of ocean acidification.

**S9-P7**

**Reconciling ocean productivity and fisheries catch in a changing climate**

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Photosynthesis fuels marine food webs yet differences in fish catch across marine ecosystems far exceed differences in net primary production (NPP). In this recently published work (PNAS, 114(8)), we examine drivers of this contrast by combining global fish catch and fishing effort data with flows of energy from the plankton food web from a prototype high-resolution global Earth System Model (ESM). Stark inter-regional differences in fish catch per unit area can be explained with an energy-based model that a) considers dynamic inter-regional differences in benthic and pelagic energy pathways connecting phytoplankton and fish, b) depresses trophic transfer efficiencies in the tropics, and c) associates elevated trophic transfer efficiencies with benthic-predominant systems. Model catch estimates are generally within a factor of two of values spanning two orders of magnitude. The same mechanisms explaining dramatic regional catch differences in the contemporary ocean amplify projected catch trends relative to NPP, suggesting the potential for regional catch changes exceeding 50% in some regions under high emissions scenarios.

## S10: Management and Conservation of Species on the Move

### S10-P1

#### Climate and resource variation differentially affect intrinsic population processes to drive patterns of seabird population dynamics in UK coastal waters

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A key concept in the study of animal population dynamics is to understand how deterministic and stochastic processes interact to shape the abundance of animals over time and space. An emerging tenet from terrestrial macroecological studies has demonstrated both positive (temporal variation in climate) and negative (spatial variation in food resources) relationships between environmental stochasticity and the strength of direct density dependence in populations. However, these relationships are yet to be tested in marine systems for higher trophic level species. We developed state space Ricker population models for 11 species of breeding seabirds in UK waters using time-series of colony counts dating back to the 1960s from the Seabird Monitoring Program. These models estimated both the intrinsic rate of population increase and the strength of direct and delayed density dependence in each population. We then correlated the relative strength and spatial pattern of density dependence with different sources of environmental stochasticity such as temporal variation in climate, spatial variation in resources, synchronicity of resources and community structure. We identify some striking spatial patterns in the strength of direct and delayed density dependence in UK waters, which are consistent across several of the species studied. We also demonstrate the complex nature of potentially counteractive forces of environmental stochasticity on population dynamics in these species. Our results have important implications for understanding how climate change is affecting population dynamics of seabirds, and how characteristics of the marine environment may help to buffer the impact of climate change on these iconic species.

### S10-P2

#### Climate-driven abundance and distribution variability of winter-spring cohort of neon flying squid *Ommastrephes bartramii* in the Northwest Pacific Ocean using habitat suitability modeling approach

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A habitat suitability index (HSI) model was developed to examine the climate-related habitat variations and the relationship with abundance and distribution of neon flying squid *Ommastrephes bartramii* in the Northwest Pacific Ocean. The HSI model was constructed and validated using the fishery data during 2006-2015 with three crucial environmental variables including sea surface temperature (SST), photosynthetically active radiation (PAR) and sea surface height anomaly (SSHA). Results indicated that the catch-per-unit-effort (CPUE) of *O. bartramii* gradually decreased during 2006-2015, the latitudinal gravity centers of fishing effort (LATG) shifted southward. Correlation analyses suggested that the CPUE was positively correlated with SST, PAR and the areas of suitable ( $HSI \geq 0.6$ ) and optimal ( $HSI \geq 0.8$ ) habitats occupying the whole fishing ground, but negatively related to the SSHA. Significantly positive correlation was found between the LATG and the average latitude of the most preferred SST, PAR, and the average latitude of the area with the HSI between 0.9-1.0. The annually declining CPUE over 2006-2015 were highly consistent with the expansive poor habitats and contractive suitable and optimal habitats. Meanwhile, the south-approaching LATG coincided with the southward migration pattern of the latitude of area with HSI in the range of 0.9-1.0. Moreover, comparing to the El Niño events, La Niña events yielded higher CPUE and enlarged suitable habitat areas for *O. bartramii*, the LATG moved toward further north. Our findings suggested that variability in the abundance and distribution of *O. bartramii* were largely attributed to climate-induced massive environmental variations and further habitat changes on the fishing ground.

## S10-P3

### Past and projected changes of the suitable thermal habitat of North Sea cod under climate change

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Most of our knowledge about geographical changes of fish habitat derives from coupling global climate models with habitat models. However, global models are unable of correctly resolving changes of temperature occurring on smaller, regional scales. We present here, to our knowledge for the first time, results of a temperature-dependent fish habitat model coupled with a *regional* climate model. The habitat model is based on a generalized additive model between North Sea cod abundances from the International Bottom Trawl Survey (IBTS) and observed bottom temperature maps from 1967-2015. To deal with aliasing (a major source of noise relating the sampling space scale) of fish-schooling variability, we match the temperature fields with abundance maps from a hurdle model instead of with raw IBTS data. We then project the past abundance changes onto the future (2020-2100) using temperature fields of the Max Planck Institute Ocean Model, with a particularly large resolution in the North Sea, under the IPCC scenario RCP8.5. Our results show that, following a temperature increase of ca. 1°C in the shallow regions of the North Sea from 1967 to 2015, there is mostly improved cod habitat suitability in large parts of the North Sea, with a maximum increase of roughly 30% in Skagerrak. Decrease of ca. 5% habitat suitability occurs only south of 54°N. This distribution of suitability changes will roughly continue under climate change until 2100, with habitat suitability further increasing in the eastern Norwegian Trench and decreasing in the southern North Sea.

## S10-P4

### Creating a climate science toolkit to inform management decisions for threatened and endangered species

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The Offices of Protected Resources and Science and Technology of NOAA's National Marine Fisheries Service (NMFS) are collaborating on the creation of a climate science toolkit to assist staff with access to climate science data and tools to fulfill their responsibilities under the Endangered Species Act (ESA). Staff engaged in ESA-related research, recovery activities, consultations, and other conservation actions participated in a survey to determine how climate-related information is used, what additional data and tools are needed and at what spatial and temporal scales, and what training might be needed to assist staff in using the information in the toolkit. Survey results indicated that climate-related information is a high priority need to enable staff to understand the potential impacts of physical changes on protected species and their habitats including potential distribution and habitat shifts particularly at regional, sub-regional, and local scales over the next 2-10 years and 20-50 years. The Greater Atlantic and West Coast Regions were selected as pilot areas for the climate science toolkit. The goal is to have the toolkit ready for regional testing by September 2018. The toolkit will be accessible through a Google site all NOAA staff can access and climate-related reference materials will be linked to the site likely through a cloud-based Endnote library. Training materials will also be included in the toolkit for staff to learn how to use data and tools in their work. We present key survey results that informed toolkit development and a brief demo of the pilot toolkit.



## S10-P5

### Out of tuna: Using metabolic models to estimate future accessibility of bluefin and yellowfin tunas to U.S. fisheries

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Climate change is likely to drive complex shifts in the distribution and ecology of marine fishes, depending on their physiology and life histories. Large tunas (*Thunnus* spp.) are highly migratory with broad thermal tolerances, and they support productive fisheries from tropical to sub-polar environments in all major oceans. Previous research has suggested that tunas may preferentially occupy thermal environments which maximize metabolic scope, and that these relationships are species-specific. In this study, we use published experimental data to build mechanistic oxygen balance models for yellowfin (*T. albacares*), and bluefin (*T. thynnus*, *T. orientalis* and *T. maccoyii*) tunas. We show how predicted favorable metabolic habitats overlap with regions of high catches for each species, using catch data from regional fisheries management organizations around the world. Projections from an Earth System Model (GFDL-ESM2M) suggest future poleward movements of favorable habitat for tunas, in association with warming temperatures and deoxygenation. Using fisheries landings data from the United States, we project likely changes in accessibility of both yellowfin and bluefin tuna to U.S. fisheries by state, along the Pacific, Atlantic, and Gulf of Mexico coasts. We then show how optimal locations of U.S. fishing ports may change in the future, using projected distribution shifts of target tuna species, and typical range characteristics for longline and troll fishing vessels. Implications for climate vulnerability of different fishing ports are then discussed, along with some likely management implications.

## S10-P6

### Squid on the move in a marine climate change 'hotspot' and why it matters to fisheries and society

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Substantial warming of the North Sea has led to a reorganisation of marine communities, with many species showing northward distribution shifts, and warm-water species generally having become more abundant compared to cold-water species, many of which have declined. Given that the latter include many finfish species traditionally targeted by fisheries but under strict quota restrictions, fisheries have responded by increasingly targeting alternative, non-quota species, and squid catches have increased dramatically in recent decades. Here we show that squid have shown a substantial range expansion in the North Sea in the last 35 years, and that climatic variables – notably sea surface temperature and the Atlantic Multidecadal Oscillation – were very closely linked to increased squid presence. For future decades, modelling studies predict that within UK waters, the habitat suitability for European and veined squid, the main target species, will greatly increase (median estimates +31% and +7%, respectively, from 1985–2050), more than for most finfish species examined. With squid predicted to end up as beneficiaries from climate change where many finfish struggle, fisheries are expected to adapt accordingly, and seafood products based on squid may increasingly be represented in the diet of UK citizens.

## S10-P7

### Management solutions for shifting trans-boundary fish stocks under fixed catch shares

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Rising sea water temperature is driving many fish stocks to move poleward. As more evidences emerge, it becomes increasingly imperative to seek for adaptation strategies to avoid over-exploitation of shifting fish resources and the dissipation of economic rent. In this paper, we first show quantitatively why adaptation strategies are necessary, followed by demonstrating that a fixed catch share scheme can be a practical solution to minimize the impacts in transboundary stocks. We tackled our research questions in a two players' non-cooperative model, where both players share a fish stock that moves from the EEZ of one country to the other due to water temperature increase. A dynamic programming algorithm is used to identify closed-loop Nash strategies, in which players are able to adjust periodically harvest policy according to stock levels. We show that the stock is exploited to a minimum level during the stock transition, as over-exploitation is at its fiercest when two players have similar stock share. To avoid this, we propose a fixed catch share (FCS) scheme where the two countries meeting annually to agree upon a specific catch share for as long as the stock is shared, until one of the countries opts out. The adaptation policy proposed mimics existing quota negotiation processes in accordance with the stability key principle that is practiced by the EU common fisheries policy. We demonstrate that this adaptation policy accounts for the stability of a coalition, assuring the sustainability of the shifting stocks and the rent from fisheries.

## S10-P8

### Climatically-induced change in ocean circulation as a potential stressor of marine ecosystems

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Conventionally, the major anthropogenic stressors of marine ecosystems are considered to be ocean warming, acidification, deoxygenation and decreased productivity. However, alongside these changes, ocean circulation itself is changing in response to climate change, and can be considered an additional potential stressor. Changes in the location and strength of the western boundary currents have already been observed, together with evidence of the resulting impacts for ecosystems. Here, we investigate the potential impact of climatically-induced change in ocean circulation on propagule dispersal, using a high-resolution global ocean general circulation model run under the high end-member RCP 8.5 scenario. The resolution of this model permits improved regional realism beyond that of available CMIP5-class models. Our approach uses a Lagrangian methodology, in which virtual propagules are forced by modelled circulation pathways, simulating the dispersal of planktonic life stages. We distribute these propagules worldwide in coastal regions, and backtrack their trajectories to identify coastal retention, dominant flow patterns and dispersal ranges at the global scale. Initially, we focus on the present-day situation, before projecting into the future to identify areas with the greatest circulation change. We additionally examine select regional examples with the most significant changes to their current circulation pathways. From this, we argue that climatically-induced circulation change must be considered as an additional potential stressor of marine organisms.

## S10-P9

### Winter is (not) coming: Changes to overwinter behavior of blue crab, *Callinectes sapidus*, in response to warming temperature

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Understanding how increases in water temperature may effect winter dormancy period duration and overwinter survival are important for the effective conservation and management of estuarine species in the face of a warming climate. In this study, the length of the overwintering period and the probability of overwinter survival of blue crab (*Callinectes sapidus*), an ecologically and economically important estuarine crustacean, were determined. Overwintering period length and probability of overwinter survival were determined using water temperature predictions up to the year 2100 which were derived from a harmonic model that utilized air temperatures predicted in multiple regional-scale climate projections. Estimates of warming water temperatures by 2100 in Chesapeake Bay indicate that the overwintering period in this species will be up to 50% shorter and overwinter survival will increase by at least 20% compared to current conditions. The warmer conditions will lead to faster and prolonged seasonal growth, which, when combined with lower winter mortality, will lead to increased population productivity. The level of expression of this increased productivity will depend on the response of other elements of the Chesapeake Bay food web, and on the response of fishery management policies.

## S10-P10

### A climate vulnerability assessment for marine mammals in the Northwest Atlantic, Gulf of Mexico and Caribbean

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Climate change is expected to influence the distribution, abundance, and phenology of many species in marine, coastal, and estuarine ecosystems. The implications of changing conditions for conservation and recovery may be more substantial for protected species populations, which are already at high risk due to a variety of stressors. Quantifying climate impacts is further complicated for highly mobile species such as marine mammals. NOAA Fisheries began implementing a method to assess the vulnerability of marine mammal stocks to climate change in the Northwest Atlantic, Gulf of Mexico, and Caribbean in late 2017. The results will be used to provide managers with a list of vulnerable stocks and reasons for risk determination. The method, based on frameworks used for other marine taxa (fish and invertebrates), provides an approach that uses empirical data and expert judgement to assess marine mammal exposure, sensitivity, and capacity to adapt to climate change. By jointly assessing current life history traits, current distributions, and projections of future climate and oceanographic conditions, the assessment produces relative vulnerability scores for each stock, provides information on significant attributes contributing to the stock's vulnerability, and identifies key information gaps. Such assessments provide forward-looking qualitative outlook of potential stock changes in abundance, distribution, and phenology that can inform future management actions and identify research priorities. We present the preliminary results from the assessment, outputs and products that will be provided to managers to incorporate into decision-making, and lessons to apply in other geographic regions.

## S10-P11

### **Understanding the past and predicting the future of the North-east Atlantic “Mackerel War”**

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Dramatic shifts in the distribution of Mackerel in the North-eastern North Atlantic in the late 2000s led to international conflicts over fishing rights in the region: the so-called “Mackerel War” has been described by some as the most severe conflict between Nordic nations in the last 200 years. Understanding the mechanisms that drove these shifts is of high importance for the management of the North Atlantic basin and is also key to both foreseeing what the future holds and preparing accordingly. While there has been an automatic tendency in the literature to attribute these shifts to climate change, I will show that the reality is much more complex: the vagaries of migration dynamics and population-level processes also have played a critical role. Here I will review the history of this conflict and assess the relative importance of each of these mechanisms, thereby identifying the ultimate cause of the Mackerel conflict. I then apply this knowledge together with advances in the fields of oceanographic prediction to develop a multi-annual early-warning system that can potentially be used to assess the risk of such shifts reoccurring. Such a system can aid both management and decision-making in this region and therefore potentially contribute to avoiding a repeat of this conflict in the future.

## S10-P12

### **Capital investment for optimal exploitation of renewable resource stocks in the age of global change biology**

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The world is rapidly changing, and people must adapt to changes in the amount and spatial distribution of natural capital including fish stocks. One option is to change the way people interact with natural capital, for example changing harvest levels of fisheries. Alternatively, people can invest in reproducible or human capital, which may be a substitute or complement for the fish stock. The economic and ecological details of the system jointly determine the optimal investment in human capital as well as investment decisions in natural capital. This is particularly relevant to fisheries facing climate change and the spread of invasive species. We investigate investment in capital that enables targeted ecological management using a simplified bioeconomic model that includes two interacting species. We characterize the optimal effort levels and investment in targeting over time as one species invades the habitat of the original species for four stylized bioeconomic scenarios. We find that price differences among species are particularly important to driving differences in investment in targeting capital and overall ecosystem outcomes.

## S10-P13

### Effects of climate change on growth and migration of Pacific saury (*Cololabis saira*) in the North Pacific

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Pacific saury (*Cololabis saira*) is a pelagic fish species widely distributes in the North Pacific. We have evaluated climate change (global warming) effects on saury by integrating a fish-migration and growth model using environmental conditions derived from simulations of a coupled ocean circulation and ecosystem model with contemporary and future climate forcing. For the ocean circulation model, a high resolution (1/10 deg.) ROMS (Regional Ocean Modeling System) was used. For the marine ecosystem model, eNEMURO, an extended version of NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) was used. For climate forcing, the output of MRI-CGCM3 with RCP2.6, RCP6.0 and RCP8.5 scenarios were averaged during 2011-2020, 2051-2060 and 2091-2100 and the FRA-ROMS-eNEMURO was integrated with those climatological forcing. A fish-migration and growth model (FRA-ROMS-eNEMURO.FISH) was integrated by the output environments. In FRA-ROMS-eNEMURO.FISH, super-individual based modeling (S-IBM) approach was introduced which enables population fluctuation with size dependent mortality. The initial spawning grounds were estimated based on the sea surface temperature (SST). The spawning grounds shifted to northward under warming conditions. The migration routes were also modified both by direct SST influence and indirect effect by prey plankton availability. The migration population from autumn and winter spawned cohorts was decreased while one from spring spawned cohort was increased under the warming condition. In total, migration population to Japan was increased, however the fish size was reduced under warming conditions. Since the price of saury highly depends on fish size, global warming might severely impact on saury fisheries in Japan.

## S10-P14

### Assessing the impact of climate change on marine top predator populations

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Numerous Earth climate model forecasts for global ocean are now available to explore the impact of climate change on exploited marine resources. We use the Spatial Ecosystem And Population Dynamics Model (SEAPODYM) to investigate the potential impact of climate change and fishing on four tuna populations in Indian and Pacific oceans. SEAPODYM provides spatially explicit representation of population dynamics integrating relationships between fish movement and the environmental variables, and includes a robust estimation approach of population dynamics and fisheries parameters. The modeling framework allows including various scenarios, e.g. to investigate the impact of ocean acidification on the early life stages of tuna, consider uncertainty on key variables (dissolved oxygen and temperature) driving recruitment and conditioning fish habitat. Also, most recent projections are obtained from multiple simulations of climate models of the 5th IPCC Coupled Model Intercomparison Project, thus providing an envelope of prediction. These modeling studies have shown various responses of tuna species to changing climate. The core habitat of most tropical species as skipjack and yellowfin are predicted to shift from western to central and eastern equatorial Pacific, while the more temperate albacore tuna would have their spawning grounds shifted poleward suggesting modification of adults' migration routes. Bigeye tuna biomass is projected to decrease significantly under all RCP8.5 ("business as usual" scenarios) simulations advocating for immediate management and conservation measures to rebuild the stock at a higher biomass level than the present one.

## S10-P15

### Differences in groundfish distributional changes across NE Pacific shelf: Subregion, species, and life history

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It has been increasingly recognized that many marine species shift location with changing ocean conditions. However, fish horizontal and vertical movement structure, including both ontogenetic shifts and response to temperature, remains unknown. Here we report the ocean conditions and distributional changes in ten abundant groundfish species based on large datasets of summer depth-stratified random bottom trawl survey in the Gulf of Alaska, Canada west coast and US west coast. We minimized spatio-temporal bias due to the extensive survey process by classifying the three surveys into nine subregions where the surveys were conducted at the same time of the year of each other and completed within one month. We used size bins to capture ontogenetic differences and estimated the abundance and stratum area-weighted centroids in latitude, longitude, depth and temperature for each species in each size bin. We applied multivariate analyses to examine the structure of fish movements which included two types of movements, ontogenetic shifts and responses to temperature anomalies, in terms of depth, longitude and latitude. Principal Component Analyses (PCA) results show that the primary movements tend to be ontogenetic shifts in depth. The warm and cold years varied from subregion and fish responses to warm temperatures also varied substantially from subregion. This study highlights the important role of local dynamics in shaping fish movements.

## S10-P16

### How regional fishery bodies have responded to climate change

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This is the first global survey of Regional Fishery Bodies (RFB) responses thus far to the current and predicted future effects of climate change. Fisheries management is highly dependent on the regularity in space and time, within ecological boundaries, of targeted fish populations. Oceanic climate-driven changes are leading to continuing deviation from this regularity. Around the world ocean are areas of measurably faster warming sea surface temperatures, 'hotspots', which can provide potentially strong indicators of the direct effects of climate change. We assessed the annual reports of 17 RFB over the period 2002 – 2016, looking for the phrase 'climate change' and the context in which the phrase was used. Three levels of institutional engagement were developed: Awareness of climate change; Learning about climate change; and then any Action taken by the RFB. Of the RFB examined, 88% of institutions demonstrated awareness of climate change; 82% demonstrated learning about climate change; while only 41% demonstrated some form of action, but these were mainly procedural and administrative. Over the last 14 years, the gap between 'awareness' and 'action' was actually growing, i.e. awareness was increasing steadily and yet action remain stagnant. Only two of the RFB examined made explicit statements about incorporating climate change into future fishing management plans. The inference is that most RFB are largely practising business-as-usual, with the implication that fish populations under industrial fishing will continue to experience maximal fishing effort as the sea around them alters.

## S10-P17

### Historical dynamics of the demersal fish community in the East and South China Seas

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Taiwan has long history of fishery operations and contributes significantly to global fishery catch. However, datasets containing spatial and temporal abundances gleaned from these operations are typically not publicly available. In this study, we digitize historical catch records from government fishery reports for nine commercial species caught by otter trawl, reported monthly from 1970 to 2001 from the East and South China Seas. We apply a model that estimates covariation in multispecies catch rates, attributed to spatial habitat preferences and environmental responses, and which estimates indices that represent trends in abundance and distribution shift. We find substantial spatial, temporal and spatio-temporal variation in the distribution of fishes as well as patterns that differ among seasons. Moreover, all species have high co-occurrence, and abundance trends are similar between spring, summer, and fall seasons, whereas trends in winter differ for several species. Estimates of abundance show substantial declines for 5/9 species in the spring, summer, and fall, and the center-of-distribution for these species has generally moved northeastward. We conclude by recommending collaborative work from various adjacent countries to digitize historical records of fishing catch rates.

## S10-P18

### Towards understanding changes in Pacific herring (*Clupea pallasii*) spawning distribution off the west coast of Canada over the past six decades

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Pacific herring (*Clupea pallasii*) is an ecologically- and commercially-important species in marine ecosystems off North American coast. Detailed records of herring spawn off the coast of British Columbia (BC), Canada, collected annually by fishery officers and diver teams since 1928, indicated that both spawning distribution and abundance had gone through systematic changes over the time. The cessation of spawning in some areas has led to concerns that the herring roe fishery has resulted in serial depletion of local spawning populations. However, previous studies suggested that spawning fluctuations may not necessarily be caused by fishery; there have hitherto been no satisfactory explanations for these changes. In this study, we used a series of observed basin-scale indices (Pacific Decadal Oscillation and North Pacific Gyre Oscillation) and regional-scale outputs (COADS wind stress) off the BC coast to explore linkages between environmental conditions and herring spawning distribution. A boosted regression tree (BRT) model was developed to examine the nonlinear dynamics between environmental indices and spawning indices from four major spawning regions in BC (Prince Rupert, Haida Gwaii, Central Coast, and West Coast Vancouver Island). The results suggest that except for Haida Gwaii, PDO and upwelling favored wind stress are top contributors for spawning fluctuations. At Haida Gwaii, herring spawning is primarily governed by downwelling favorable wind stress. These results facilitate our understanding how changes in environmental conditions affect herring spawning success and subsequent population dynamics.

## **S11: Benthic and pelagic system responses in a changing ocean: From genes to ecosystem level functioning**

### **S11-P1**

#### **Changes in fish community structures in seagrass beds along Pacific coast of northern Japan: Increase of species transported from southern waters**

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The area off Sanriku, Pacific coast of northern Japan, is known as one of the world's top three fishing spots. High marine biodiversity in this area is attributed to the high variability in topographical, physical and chemical conditions within a relatively small latitudinal range. Seagrass *Zostera marina* bed has been considered as an important coastal ecosystem which supports high species diversity and high biological production. The devastating tsunami following the 2011 off the Pacific coast of Tohoku Earthquake in northern Japan had huge impacts on ecosystems along the coastal area. In order to understand recent trends in habitat condition and fish community structure, vegetation and fish assemblage were investigated at three sites with different levels of disturbance by the tsunami and were compared among the three sites. After 2013, increase in abundance of two coastal species, *Girella punctate* and *Siganus fuscescens*, were observed commonly at the three sites regardless of the difference in the habitat condition. Because these two species do not spawn around these sites and are more abundant in southern waters with higher temperature, it seems that opportunity of transportation to the Sanriku coast has been increasing in the early life stages of these two species. Information on occurrence of these two species in coastal waters in other areas in Japan was summarized and used for discussion on possible effects of increase in water temperature and recent changes in physical properties of oceanic waters on the occurrence of these species in the Sanriku coast.

### **S11-P2**

#### **Effect of oceanographic change on the genetic diversity and phylogeography of a widely distributed copepod in the South Eastern Pacific**

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Copepods are key components of zooplankton in the pelagic realm. Calanoid copepods dominate the pelagic environment and can be found in highly productive areas, such as upwelling systems and oligotrophic zones, like central gyres, as the anticyclonic gyre of the South Pacific. These microcrustaceans typically have large population sizes, a high dispersion capacity, driven by physical processes, a high evolutionary potential and, in some species, a wide geographical distribution. These characters suggest that copepod populations generally tend to exhibit a low or a lack of genetic structure, with a high gene flow within their area of distribution. However, evidence has shown that various species of copepods can indeed show a strong genetic structure, with limited gene flow in populations distributed from coastal areas to the open ocean. The evidence also suggests that processes for copepod diversification are mostly controlled by changes in oceanographic conditions, such as water mass properties, presence of fronts and eddies, which can act as barriers promoting species divergence. We thus propose that the observed physical and chemical heterogeneity over the zonal gradient (cross-shelf axis), from the coastal upwelling system towards the ultra-oligotrophic central gyre in the South Eastern Pacific, can promote a significant population structuring and high genetic diversity of a widely distributed Calanoid copepod, *Pleurommama abdominalis*, driven by the intensity of the oceanographic gradients affecting their migration and dispersion. Climate change affecting these physical and chemical gradients may thus impact structure and diversity of pelagic populations.



### S11-P3 (CANCELLED)

#### **Long-term changes of marine environment conditions in the North Part of Amursky Bay (The Sea of Japan/East Sea)**

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Investigations, carried out in the coastal zone around Vladivostok, showed that slight warming of the waters of Amursky Bay at the beginning of XXI century took place. This phenomenon was accompanied by a decrease in the concentrations of dissolved oxygen; increase in phosphate concentrations in sea water and a decrease in the content of silicates and nitrates. The intensification of the accumulation of phosphates results in changing of the trophic status of the waters, which led to the restructuring of the entire water community. The changes consisted in intensifying putrefactive processes and, accordingly, in increasing turbidity of water, rising the number of bacteria, phytoplankton, *etc.* A change in the composition and structure of bottom communities in the northern part of the bay over the last 20 years was noted, which was probably caused by increased organic pollution and global warming. The effect of the latter factor leads to the introduction and acclimatization of new for the given area more warm water species. In addition, siltation of bottom sediments prevents the recovery of original bottom fauna detected at the first half of the 20th century. Silting occurs as a result of intensification of economic activity along the main watercourses.

### S11-P4

#### **Effects of climate variability on catch rate of yellowfin tuna (*Thunnus albacares*) cohort in the Indian Ocean**

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The yellowfin tuna (*Thunnus albacares*) is one of the important commercial species for longline fisheries in the Indian Ocean. In this study, we collected the records of catch rates and length measurement data of longline fisheries to investigate the association between the environmental variations and distributions for each cohort of yellowfin tuna by using empirical orthogonal function and generalized additive models. These functional associations can be used to evaluate the effects of climatic variability on the spatial pattern of the feeding grounds and spawning grounds. The results showed the distributions of juvenile (0~1 yrs) were affected by the varied of mixed layer depth and chlorophyll-a concentration, and concentrated in the northwestern Indian Ocean in the first and second quarters and moved to southwestern parts in third quarter. The change of mixed layer depth caused by Dipole Mode Index were affected the distributions of the major fishing cohort (2~3 yrs) in the first and fourth quarters in the western and central Indian Ocean. The 2~3 yrs cohorts were moved from northwestern to central Indian Ocean in the third quarters and leaved the lower sea surface temperature around the sea of Somalia. The distributions of older cohort (>4 yrs) showed the seasonal variations and mainly influenced by the varied of mixed layer depth and chlorophyll-a concentration. The results suggested that climatic oscillations were affect the suitable environments of yellowfin tuna spawning ground on Madagascar and the Bay of Bengal and feeding ground on western and central Indian Ocean.

## S11-P5

### Otolith microchemistry of Pacific cod in Yellow Sea reflects the annual and interannual variation of Yellow Sea Cold Water Mass

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The yield of Pacific cod (*Gadus macrocephalus*) in the Yellow Sea has shown an increasing trend over the past years. As a cold-water and indicator species, its distribution and growth are affected considerably by the variation of Yellow Sea Cold Water Mass (YSCWM), characterized by low temperature and high salinity. However, it is not clear yet how Pacific cod individuals respond to it at the microchemistry level. In this study, we collected 16 samples of age-0 and 15 of adult Pacific cods from a trawl survey in Yellow Sea in the autumn of 2016. Through coupling otolith increment measurement with microchemistry analysis by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), we attempted to explore the responses of Pacific cod individuals to seasonal and interannual changes of environmental conditions. The ablation points were located in the corresponding life history of cod, such as hatching, pelagic and demersal stage. For age-0 cod, Li:Ca, Na:Ca, Mg:Ca and Sr:Ca increased with the distance from the core, while an opposite trend was found in Ba:Ca, which was shown previously to be negatively correlated with salinity. The results indicated changes in ocean salinity in response to the variation of the YSCWM. For adult cod, the periodic fluctuation of Ba:Ca in otolith is a significant indication of the interannual variation of salinity within the YSCWM. Despite the fact that element value in otolith is also regulated by physiology, our results demonstrate that otolith microchemistry is a useful tool for understanding the changing pattern of the YSCWM.

## S11-P6

### Multi-decadal evolution of Ichthyofauna in trawlable bottom of the Algerian coast (South Western Mediterranean Sea)

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The Mediterranean is undergoing changes in its composition and dynamics due to global changes. New species from the Strait of Gibraltar and the Suez Canal are constantly being reported. The Algerian basin being subject to these changes, in this study, we analyze the species that have been reported and those not reported on the trawlable bottom of the Algerian coast, from 20 to 800 meters deep, using data from 5 stock assessment surveys performed between 1982 and 2012. The preliminary results show that 27 exclusively osteichthyes species have appeared over time, most of these species have Atlantic origin, this may mean that the Algerian coast is more influenced by Atlantic waters than by those of the eastern basin. Moreover, 12 species of chondrichthyans and 32 species of osteichthyes were not recorded in 2012, as compared to 1982. We investigate the possible causes for these appearances and disappearances in relation to overfishing and temperature changes (and other ecological parameters when available).

## S11-P7

### **Diving deeper into the algal holobiont: Exploring effects of environmental changes on bacterial diversity**

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Microbial interactions have been linked to the ecological success of marine algae and may, at least partly, be responsible for the competitive advantage of invasive species. Bacteria form a complex network of interactions with their respective host as well as with other bacterial taxa. It has been shown that in *Caulerpa cylindracea*, a notoriously invasive green alga, rich intracellular endosymbiotic bacterial communities exist, as well as epiphytic bacteria forming a biofilm layer surrounding the alga. These communities, separated by the cell membrane, are different in nature and perform specialised functions. The structure and assembly of these communities are subject to abiotic factors such as temperature and nutrient availability. Therefore, changes in the *C. cylindracea* microbiome could alleviate stress caused by abiotic factors and allow adaptation to the effects of climate change. To further disentangle bacterial assembly and functional diversity, *in situ* experiments were performed to simulate temperature stress as well as increased nutrient load. An approach combining 16S rDNA meta-barcoding and whole genome shotgun sequencing were used to elucidate the microbiome structure of *C. cylindracea* and how alterations in environmental abiotic conditions effect bacterial diversity and function.

## S11-P8

### **Return of the dead zone: Severe hypoxia observed off Oregon and Washington during the 2017 West Coast groundfish bottom trawl survey**

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Seasonal hypoxia has occurred in near-bottom waters off the Oregon continental shelf since 2002. Potentially linked to shifts in climate and upwelling, the severity of these hypoxic events has varied considerably over time. In 2017, the West Coast Groundfish Bottom Trawl Survey encountered severe hypoxia in shelf tows with depths ranging from 62 to 160 m off the coasts of Oregon and Washington. Near-bottom dissolved oxygen levels (DO) as low as 0.10 ml l<sup>-1</sup> correlated strongly with reductions in catch and species richness. Large quantities of decomposing Dungeness crabs encountered in other areas suggested that these hypoxic conditions may have been widespread and resulted in local die-offs of benthic invertebrates. We examine the extent and intensity of near-bottom hypoxia observed in 2017, analyze catches of groundfish and invertebrates from oxygen-poor locations, and explore environmental factors that may have contributed to the severity of this phenomenon in 2017. Our prior research revealed significant positive relationships between catch and DO for 19 of 34 groundfish species within hypoxic bottom waters using generalized additive models. We utilize an expanded time series (2008 to 2017) to examine similarities and differences in the response of various subgroups of groundfish species to low DO levels, information of value to future ecosystem-based management in the face of changing oceanographic conditions.

## S11-P9

### The possible influence of climatic variation on the catch of grey mullet (*Mugil cephalus* L.) in the Taiwan Strait

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Grey mullet (*Mugil cephalus* L.) is one of the important commercial species in the coastal fisheries of Taiwan. It was recorded that the spawning and nursery grounds are distributed in the coastal waters of the southeastern Taiwan Strait (TS). For previous studies, it has been speculated that climate variability and rising SSTs caused by global warming have impacted the migration and catch rates of mullet. It has also been speculated that rising SSTs affect the migratory stock of mullet and push the fishing grounds further north and further south. In this study, we analyzed the unique long-term (1912–2016) records of mullet caught in the TS to investigate the influences of multi-timescale climatic indices on the annual catch of mullet. In recent years, its population has rapidly declined, causing concerns for the local management agency. After the 1990s, fishermen attempted to maximize manpower resources and reduce costs. They gradually changed the fishing gear from purse seine to gill nets. The wavelet analysis revealed that variations in climatic indices, Pacific Decadal Oscillation (PDO), the Oceanic Niño index and sea surface temperatures, might have affected the abundance and migration behavior of mullet in the TS in winter. The results showed that PDO affects the migration of mullet, but that increases in SSTs are a more important influence on the decreased catches of mullet after 1980. Furthermore, distribution areas of grey mullet were pushed further to the southern TS by following strengthened southward of the North Coastal China Current during the La Niña events, resulting in increased vulnerability of this species to surface fisheries in this region in winter.

## S11-P10

### Is *Corallina officinalis* (*Corallinales*, *Rhodophyta*) able to adapt to environmental conditions across its geographic distribution?

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Coralline algae are critical components of marine shallow water ecosystems where they function as important ecosystem engineers. In this study, physiological responses of *Corallina officinalis* were investigated across its natural distribution in the North Atlantic. Samples were collected from northern (Iceland), southern (Spain) and central (UK) populations, slowly acclimatised to the conditions of the other population's environments in the lab and cultured for 3 months. Physiological measurements of calcification, photosynthesis and respiration were performed using closed cell respirometry methods. Analysis via LA-ICPMS were performed to determine changes in elemental compositions of their magnesium calcite skeletons. Photosynthesis, respiration and calcification of British populations (BP) kept in Spanish conditions (SC) showed an overall decrease. The most affected physiological process was calcification, with thallus dissolution both in the dark and in the light. Mg/Ca ratios of BP in SC decreased by ~25%. Photosynthesis, respiration and calcification of the Spanish populations (SP) in British conditions (BC) showed an overall decrease, with a reduction of 200% in photosynthesis and respiration. Mg/Ca ratios of SP in BC decreased by ~38%. Photosynthesis rates of Icelandic populations (IP) kept in BC condition decreased by ~50% while respiration rates showed an overall increase. Light calcification rates stayed stable in all treatments while dark calcification rates decreased drastically. Mg/Ca ratios of IP decreased in BC and SC by ~35% and ~20%, respectively. This data, which can be used as baseline data, shows that northern margin populations of *C. officinalis* may be more resilient to climatic changes, contrary to general assumptions.

## S11-P11

### New insights into early oocyte dynamics and their links to environmental cues challenge assumed fecundity pattern and reproductive potential

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Understanding the controls of biological processes is crucial to forecast productivity changes, especially in a context of climate change. Certain short term environmental conditions and regime shifts may lower fish stocks recruitment. Oogenesis and fecundity are in the base of complex interactions of factors resulting in stock recruitment. The selection of the appropriated method to estimate egg production (*i.e.* annual potential fecundity) is based on the type of fecundity (*i.e.* indeterminate vs. determinate), but despite its relevance for reproductive ecology, the fecundity pattern still remains uncertain for many stocks. Moreover, early oocyte recruitment, which relates to fecundity pattern has rarely been assessed due to its complexity, especially in indeterminate species with protracted spawning season. Using European hake (*Merluccius merluccius*), one of the main commercial species in Southern Europe, as a case study we applied advanced methodology to calculate oocyte packing density and examine temporal early oocyte recruitment dynamics tracking key stages. Subsequently, the oocyte dynamics were contrasted to the fluctuation of environmental factors. Our work shed new light on oocyte recruitment dynamics and environmental cues likely involved suggesting that photoperiod act as a trigger of early recruitment and temperature and upwelling processes as regulators of oocyte production and spawning. Further to this, the findings point to a switch of fecundity pattern across the annual cycle in this species and, from a broader perspective, it challenges the assumed conception of fecundity type, which would ultimately have strong implications on fisheries biology and management.

## S11-P12

### Effects of ocean acidification on sharks

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New studies have been evaluating the potential effects of end-of-century elevated CO<sub>2</sub> levels on sharks and their relatives' early development, physiology and behaviour. Here, we review those findings and use a meta-analysis approach to quantify the overall direction and magnitude of biological responses to OA in the species of sharks that have been investigated to date. While embryo survival and development time are mostly unaffected by elevated CO<sub>2</sub>, there are clear effects on body condition, growth, aerobic potential and behaviour. Furthermore, studies to date suggest that the effects of OA could be as substantial as those due to warming in some species. A major limitation is that all past studies have involved relatively sedentary, benthic sharks that are capable of buccal ventilation – no studies have investigated pelagic sharks that depend on ram ventilation. Future research should focus on species with different life strategies (*e.g.*, pelagic, ram-ventilators), climate zones (*e.g.*, polar regions), habitats (*e.g.*, open ocean), and distinct phases of ontogeny in order to fully predict how OA and climate change will impact higher order predators and therefore marine ecosystem dynamics.

## S11-P13

### Exposure to elevated temperature reduces effects of acidification on inducible defenses in the blue mussel, *Mytilus edulis*, during predator crab exposure

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Increased temperature, pCO<sub>2</sub> and reduced  $\Omega_{\text{Arag}}$  under anticipated marine climate change along northwest Atlantic coasts may require greater energetic investment in calcification to maintain shell growth within the blue mussel, *Mytilus edulis*. Such energetic investment may result in metabolic trade-offs, limiting inducible defenses during exposure to crab predators, complicated by potential interaction between increased temperature and reduced ambient pH. For example, elevated temperatures may ameliorate deleterious physiological effects of acidification within prey. To assess effects of climate change on predation vulnerability, we quantified the effects of high temperature and pCO<sub>2</sub> on byssal production, an inducible defense, in blue mussel prey when exposed to a crab predator in the Gulf of Maine. Mussels were acclimatized to treatment conditions (12, 18°C; 380, 500, 1000 ppmv) using a CO<sub>2</sub>-dosing ocean acidification aquaria system. Juvenile mussels (<5 cm) were exposed to a single Asian shore crab (*Hemigrapsus sanguineus*) separated by mesh. Mean number of byssal threads per mussel and attachment strength to experimental tiles was quantified. Byssal number and attachment strength in juvenile mussels were greater during exposure to crab predators. However, such effects during predator exposure were reduced under elevated pCO<sub>2</sub> conditions at low temperature compared to those under elevated temperature and pCO<sub>2</sub>. Study results support previous experimental results suggesting significant effects of ocean acidification on inducible defenses, and that rising ocean temperature may influence the magnitude of anticipated impacts of acidification on prey behavior. Quantifying how anticipated shifts in both temperature and acidification may affect prey vulnerability in calcifying organisms is vital to understanding potential climate-driven shifts in trophic relationships and community dynamics within intertidal habitats.

## S11-P14

### Effects of multiple thermal stresses on chlorophyll-*a* content and size of *Cassiopea andromeda* (Cnidaria: Scyphozoa) and the role of heterotrophy and *Symbiodinium* concentration

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Bleaching is defined by the disruption of the symbiotic relationship between the host and *Symbiodinium* dinoflagellates and has been linked to seawater temperature elevation. These events are becoming more intense and frequent. Therefore, it is important to understand if the effects of these stress events are cumulative on this symbiotic relationship. We experimentally tested how the *Symbiodinium*-associated jellyfish *Cassiopea* sp. is affected by three consecutive thermal stress events, monitoring umbrella size and chlorophyll-*a*. Jellyfishes in four physiological conditions regarding feeding frequency (daily and every three days) and *Symbiodinium* concentration (low and high) were subject to a one-week thermal stress at each experimental round. Three treatments were applied: 27°C (control), 30°C and 33°C. After a three-week recovery period at 27°C, the thermal stress events were applied on two more instances intertwined by a recovery period. Chlorophyll-*a* decreased for all temperatures during the first thermal stress and only at 33°C for the second and third. Size was only affected by feeding and by the second thermal stress. The scenario of low *Symbiodinium* concentration and low food offer resulted in an increase of chlorophyll-*a*. At high *Symbiodinium* concentration and high food offer, there was a decrease in chlorophyll-*a*. Higher food offer caused organisms to increase in size while those offered a low amount of food decreased. We concluded that multiple stress events affect the symbiont, not the host, which seems to rely more on heterotrophic feeding, and the photosymbiosis may play a much less important role to the jellyfish than to scleractinian corals.

**S11-P15**

**Interactive effects of temperature and acidification on pteropods in the California Current Ecosystem during 2016 El-Niño**

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Pteropods are zooplanktonic pelagic snails with thin aragonite shells that makes them vulnerable to ocean acidification (OA). The effects of corrosive waters on pteropod shell dissolution are well documented, making them useful indicator of the declining habitat due to OA. However, the interaction of OA with other stressors such as temperature have hereto not been observed in the CCS. During the NOAA cruise at the early upwelling season in May 2016, pteropods were entirely missing in the large area stretching over 1000 km across the Central and Northern California. Following ‘the Blob’ event, strong El-Niño in 2014-2015 created anomalously warm water conditions. At the same time, strong upwelling along the Californian coast enhanced ocean acidification, simultaneously exposing pteropods to co-occurring of temperature and acidification stress, which was unprecedented during the last few decades. We investigated the effect of temperature and OA stress on pteropods, incorporating an oxidative stress study that can provide a mechanistic understanding of pteropods stress response in the natural environment. Experimental study showed combined stressor to additively increase pteropods mortality, while the cellular stress response demonstrated increased oxidative stress levels. The responses were associated with specific temperature and OA, allowing the synthesis of the relevant pteropod thresholds in the CCS. We integrated these results into habitat niche model to make future prediction about habitat compression along the CCS due to multiple stressors.

## **S12: Scenarios and models to explore the future of marine coupled human-natural systems under climate change**

### **S12-P1**

#### **Biophysical responses to ocean acidification and impacts on global fisheries**

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Increased atmospheric carbon dioxide (CO<sub>2</sub>) concentrations alter ocean chemistry, causing ocean acidification and affecting marine species and the ecosystem goods and services provided to human society. Ongoing ocean acidification research provides modellers with valuable information and tools for constructing projection scenarios of elevated atmospheric CO<sub>2</sub>. By integrating the effects of ocean acidification as impacts on growth and mortality, we used spatially explicit species distribution models to project the impacts of ocean acidification in a multi-stressor framework on commercially exploited marine species. Temperature was the main driver of distributional shifts to higher latitudes, while ocean acidification had largely negative impacts on the biomass of invertebrate fisheries catch potential. Globally, invertebrate fisheries catch potential decreased 12.5% by the end of the century, of which ocean acidification effects accounted for about 3.5% — but impacts varied by region. For example, in Canada's Arctic region predicted to be highly vulnerable to ocean acidification, invertebrate fisheries catch was projected to increase 25% by the end of the century due to species invasion in response to ocean warming. However, this increase was reduced to only 10% due to ocean acidification impacts. We highlight the importance of testing various model assumptions to address uncertainty surrounding biological ocean acidification impacts at the parameter, structural and scenario levels. Our findings underscore the utility of models and scenarios to integrate ocean acidification with other CO<sub>2</sub>-related stressors to more comprehensively assess climate change vulnerability and risk of impacts of marine species and fisheries.

### **S12-P2**

#### **Natural and land-based human factors affect the abundance of anchovy in the Gulf of Cadiz (SW Spain)**

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The Gulf of Cadiz socio-ecosystem (SW Spain) is characterized by a focal ecosystem component – the estuary of the Guadalquivir River – that has an influence on the marine ecosystem – serves as a nursery area – and at the same time concentrates a great number of sectoral human activities. This nursery role particularly affects the anchovy fishery, which is the most economically and culturally important fishery in the region. As a transition zone between terrestrial and marine environments, estuaries are particularly sensitive to human activities, either developed directly at the aquatic environment or its surroundings. A dam 110 km upstream from the river mouth regulates freshwater input (mainly for agriculture purposes) into the estuary with consequences on turbidity and salinity. Using time series analysis we (1) quantify the effects that natural (plankton, temperature, winds) and anthropogenic-influenced variables (freshwater discharges, turbidity, salinity) have on the abundance of anchovy larvae and juveniles, and (2) relate the abundance of these estuarine-resident early stages to the abundance of adult anchovy in the sea. Water management stands out as a key node where potentially conflicting interests (agriculture, power generation, aquaculture, fisheries) converge. Linking land-based activities to its impact on stock biomass represents the main challenge to ecosystem-based management in this particular regional sea. By focusing on the effects that these activities ultimately have on the anchovy fishery – via recruitment – our study aims to provide alternative management scenarios by quantifying tradeoffs between sectors.



## S12-P3

### Changes in fishmeal and fish oil supply under climate change

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Forage fishes, commonly include species from the family *Engraulidae*, *Clupeidae* and *Scombridae*, are intensely targeted by reduction fisheries and account for about 20 million tonnes of catches every year. A substantial portion of forage fish catches is used as fishmeal and fish oil in aquaculture. Thus, the sustainability and growth of aquaculture rely on the continuous supply and trade in forage fish and its products. However, climate change is threatening the supply of forage fishes from capture fisheries and may limit the future expansion of aquaculture. Here, we project future changes in maximum catch potential (MCP) of fishmeal and fish oil from forage fishes from the global oceans under scenarios of climate change. Using data from a reduction fisheries database developed by the Sea Around Us, we identified the species and estimated the proportion of their catches that had been processed into fishmeal and fish oil in each country's Exclusive Economic Zone (EEZ). We then projected future changes in these species' MCP and their potential fishmeal and fish oil production using a Dynamic Bioclimate Envelope Model. Given the increasing percentage of farmed higher trophic level species in aquaculture, we quantified the limits to continuous aquaculture development set by their demand of fishmeal and fish oil and their potential production from forage fish under climate change. The findings inform the development of scenarios of seafood supply from aquaculture under climate change, as well as the role of aquaculture in future ocean sustainability.

**Keywords:** Aquaculture, reduction fisheries, fishmeal and fish oil, food security, climate change

## S12-P4

### Effect of cod (*Gadus morhua*) predation on juvenile herring (*Clupea harengus*) in the Barents Sea

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The Barents Sea is a shelf sea sustaining a highly productive ecosystem including several commercially important fish stocks. The Northeast Arctic (NEA) cod (*Gadus morhua*), Norwegian Spring Spawning (NSS) herring (*Clupea harengus*) and Barents Sea (BS) capelin (*Mallotus villosus*) constitute key fish species in this area. Norwegian Spring spawning herring (*Clupea harengus*) is currently one of the largest herring stocks in the world, and it is both an important prey (for e.g. cod and marine mammals) and predator species (for e.g. planktonic early life stages of fish and zooplankton). It spawns in the Norwegian Sea in February-March and deposits eggs on the sea bottom. After hatching, larvae and 0-group appear in the upper water layer and drift by the coastal current to enter the Barents Sea where they spend first 3 to 4 years of life as a young herring. This species is susceptible to predation by the large stock of NEA cod. Here, we develop a state-space model to estimate the effect of cod predation on young herring mortality. In addition, we use those estimates to quantify the joint effect of fishing and cod predation at the population level. Our results indicate a significant effect of cod and illustrate how management of NSS herring benefits from jointly considering cod and fishing.

## S12-P5

### Climate-induced shift in living marine resources of shrimp trawl and small-scale fisheries in the Tropical Eastern Pacific

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Climate change is causing shifts in the biogeography of marine species, resulting in changes in species assemblages and potential fisheries catches at a global level. Hot spot of impact of climate change is assumed to be localized in the tropical biome due to the narrow thermal tolerance ranges of the species in the region, which are more sensitive to rapid changing environments. In this study, we compare climate change impacts on species targeted by two major types of coastal fisheries in the Tropical Eastern Pacific (from northern Peru to Baja California): industrial-scale shrimp trawl and other small-scale fisheries. Specifically, we examine shifting habitat suitabilities of the 550 species exploited by these fisheries under two emission scenarios (Representative Concentration Pathways 8.5 and 2.6), using three species distribution models (Surface Range Envelope, Maxent, and Boosted Regression Trees) and three different Earth System Models. We expect changes in habitat suitabilities to vary along a latitudinal gradient, with the largest decrease along the equator. We also expect climate change to impact a higher proportion of species targeted by shrimp trawl fisheries, which may lead to a higher overall risk of impacts. Climate effects on regional fish and invertebrate stocks will strongly affect national economies, societies and food security, especially in countries with greater sensitivity and lower adaptive capacity to climate change. The study's findings produce knowledge that may be actively used by decision makers to inform policies that help enhance fisheries' resilience in the face of climate change.

## S12-P6

### Potential analysis of climatic change impact on the fishing condition of tuna longline fisheries in the Pacific and Atlantic Oceans

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Tunas and billfishes are economically important species for longline fisheries in the Atlantic Oceans. Potential impacts driven by climate change on fishing conditions and environmental variability on fishing grounds were investigated in this study. Oceanographic data of four scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) from the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) were used to develop an ecological model that couples population dynamics and habitat variation. Preliminary results showed that there was an obvious seasonal variation in the distributions of mixed layer depth and sea surface temperature, but seasonal and annual patterns in net primary production and sea surface height were unclear. Results from generalized additive models (GAMs) suggested that effects of all predictor variables including year, month, latitude and longitude, and marine environmental factors were statistically significant on the catch rates of tunas and swordfish in the Atlantic Oceans. The GAMs can thus be used to predict the catch rates of tunas and swordfish for the Taiwanese distant-water tuna longline fisheries in the future. Under various scenarios of climate models, the predicted catch rates of albacore in the North and South Atlantic Ocean showed a slightly increasing trend. However, the model-predicted catch rates for bigeye, yellowfin, and swordfish in the Atlantic Ocean seem to stabilize or increase slightly in 2020.

## S12-P7

### Development of abundance index for sailfish based on data from the Taiwanese tuna longline fishery in the Atlantic Ocean

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Sailfish and spearfish are widely distributed in the Atlantic Ocean. Catch records of these two species were combined due to as non-target species in the Taiwanese tuna longline fishery in the Atlantic Ocean. However, there is a need to separate catch data of sailfish and spearfish into two species for assessment of Atlantic sailfish. Logbook data of the Taiwanese tuna longline fishery were collected in this study from 2009 to 2015, including year, month, attitude, longitude, fishing effort and catch of sailfish. We compared various methods to estimate catch ratios of sailfish in this fishery and different approaches to standardize CPUE (Catch per unit of effort) for the species, in order to develop an abundance index of Atlantic sailfish for 1968-2015. Results showed that GAMs (Generalized Additive Models) are the most appropriate methods used to estimate the catch ratio of sailfish in the fishery and that the delta-lognormal approach can deal well with large amount of zero catch data for sailfish. Standardized CPUE showed that sailfish abundance substantially decreased from the late 1960s to the 1970s and remained relatively stable thereafter. Given that the Atlantic sailfish might be overfished and large uncertainty in the assessment results, long-term series of abundance index should be developed to be used as basic input data for stock assessment to understand current stock status and the variation. Results from this study could be used to provide scientific-based suggestions for fishery management.

## S12-P8

### Projecting the abundance of eastern Bering Sea walleye pollock from a climate and trophically enhanced stock assessment model

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Walleye pollock are a commercially important fish stock in the eastern Bering Sea (EBS), and their abundance is affected by environmental conditions and predation. Variability in the extent of the summer “cold pool” (bottom water  $\leq 2^{\circ}\text{C}$ ) has resulted in variation in the spatial overlap between pollock and arrowtooth flounder, an important predator that avoids the cold pool. Additionally, sea surface temperature is related to the recruitment of age 1 pollock, with high temperatures associated with poor recruitment. A single-species population model for walleye pollock was modified to estimate a temperature-dependent stock-recruitment relationship and spatially-resolved predation mortality rates. Data on temperature, spatial overlap of arrowtooth flounder and pollock, and estimated predator consumption (obtained from spatial information on diet) were integrated to affect pollock population dynamics. The predation mortality attributed to arrowtooth flounder has increased, reflecting the increase of this predator over time. The climate and trophically enhanced pollock model was developed as part of the Alaska Climate Integrated Modeling (ACLIM) project, and is linked to projected environmental conditions obtained from a ROMS (Regional Ocean Modeling System) to evaluate potential impacts in pollock through 2100 under a range of harvest strategies and management objectives. Results from the climate and trophically enhanced model can be compared with a traditional single-species model and more complex multi-species and ecosystem models developed within the ACLIM project. Our approach also provides a statistical framework useful for evaluating the degree to which additional model complexity is supported by the additional climate and diet data.

## S12-P9

### Results from a fisheries configuration of the Madingley General Ecosystem Model

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Around 12% of the global population depend on fish for their livelihoods. The value of exported fish on the world's markets was US \$148 billion in 2014. While many fisheries are being overexploited, climate change is impacting the distribution and potential production of global fisheries. More informed management of marine living resources is required to safeguard the supply of food and income to human societies. However, mechanisms governing the stability and resilience of marine ecosystems under human pressures remain uncertain. Here, using the Madingley General Ecosystem Model, we simulate changes in global marine ecosystems under scenarios of fishing and climate change. We assess a range of indicators calculated from the model outputs, some of which are practically unmeasurable in the field, and identify a subset of useful indicators for ecosystem stability and resilience. Using these indicators, we examine the conditions, as characterized by the level of fishing pressure, climate change and available biomass, under which reduction in fishing pressure and climate change can have large effects on strengthening ecosystem stability and resilience. The findings inform the design of management and conservation measures, such as planning for Marine Protected Areas.

## S12-P10

### Potential impacts of climate change on the *Mugil cephalus* habitat in the northwestern Pacific under future RCP emission scenarios

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Grey mullet, *Mugil cephalus*, is one of the most important commercial species of fish in the coastal fisheries of Taiwan and widely distributed in the northwestern Pacific. It was recorded that the spawning and nursery grounds are distributed in the coastal waters of the southeastern Taiwan Strait (TS). For previous studies, the feeding grounds are located in the coastal and estuarine waters of China which at 25-30°N and migrates to the coastal waters of the southeastern TS for spawning in the cold North China Coastal Current in winter. We investigate impacts of climate change in fishing conditions and environmental variability of mullet fishing grounds in the coastal waters of China. Oceanography data of four scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) from the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) will be used to develop fishery resources and habitat coupled ecological models. The species distribution model for grey mullet was developed using the maximum entropy (MaxEnt) model and were identified the potential habitat in the coastal waters of China. The distribution patterns of the habitat hotspots for spawning season (winter) was separated in the western central Taiwan (Chang-Yun Rise, CYR). Because grey mullet tend to stay in 20°C of the waters, the area of higher HSI value is located in the coastal waters of western Taiwan in current year. Through ArcGIS software, we got the distribution of HSI in the study area for the spawning season. The area of high HSI value is located in CYR in current year. The western north part also have high HSI value over time (2035). In 2050, the distribution of high HSI value still shift toward eastern north Taiwan. Through the MaxEnt habitat model, we provide the scientific assessment to set the effective management strategy and may provide the references for the further study on fingerling released for our government or fishery management organization.

## S12-P11

### **Modelling the interacting effects of climate change and fisheries management on the eastern Bering Sea food web**

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The Alaska Climate Integrated Modeling (ACLIM) project is a comprehensive modeling framework that is examining how climate change may influence the dynamics of the eastern Bering Sea ecosystem and how different fisheries management actions may interact with anticipated climate change to affect fisheries. Here we present the incorporation of a climate-enhanced Ecosim model of the eastern Bering Sea food web into the ACLIM framework. Global climate models are forced with multiple IPCC scenarios and their outputs are downscaled to be coupled with a physical oceanographic-lower trophic level model (ROMS-NPZD). The outputs of the lower trophic level modelling are then used to force an Ecosim model of the eastern Bering Sea food web. A selection of harvest control rules are simultaneously applied during simulations to examine how different fisheries management actions may interact with the anticipated climate change scenarios to produce different outcomes for the ecosystem and for fisheries. We calculate a selection of ecosystem indicators, developed for the Integrated Fisheries Risk Analysis Method for Ecosystems (IFRAME) project, to track the status and trends of important ecosystem components and commercial species during simulations, and to help assess the performance of alternative fisheries management actions under the climate forcing scenarios. The results of these simulations will describe a range of potential outcomes for the eastern Bering Sea food web to the combined effects of anticipated climate scenarios and fisheries management actions, and may provide strategic guidance for fishery managers.

## S12-P12

### **From physics to fisheries: A social-ecological management strategy evaluation for the California Current Large Marine Ecosystem**

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We present a recently initiated effort to evaluate potential impacts of climate change on fisheries in the California Current Large Marine Ecosystem (CCLME). This multidisciplinary project aims to link climate to fisheries through a combination of global climate models, regional ocean models, statistical and dynamical ecological models, management strategy evaluations, and socioeconomic analyses. The project is focused on the Pacific sardine, albacore, and swordfish fisheries, with the ultimate goal of informing science-based policies that allow US federal fisheries managers to maintain a resilient ecosystem and a resilient fishing economy in the CCLME. In this talk we will give an overview of the physical, ecological, and socioeconomic modeling framework, and will discuss key issues and findings to date.

## S12-P13

### Climate change effects on fisheries-dependent communities of coastal Brazil

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The effects of climate change on Brazilian fisheries will be explored based on three sources of information: (1) a scientific literature review, (b) in-depth studies on the perceptions of small-scale fishing communities, and (3) the outcomes of a multilateral project under a Belmont Forum call with intra- and inter-national experts from different disciplines. Projections of climate change effects have shown that coastal Brazil will suffer increased impacts from large, meso and micro-scale ocean processes, as well as on fisheries productivity. Fisher's perceptions include sea-level rise and coastal erosion, shifts in wind patterns and fish distribution, alterations in livelihoods and housing infra-structure. Contributions of Project GULLS (Global understanding and learning for local solutions: reducing the vulnerability of marine-dependent communities) go beyond ocean models projections and fisher's perception, and included the construction of a social vulnerability framework and analysis, ecological sensitivity assessments, stock models, policy analysis, and education workshops. This paper aims at summarizing the main outcomes from GULLS in Brazil, highlighting the effects on community conservation and further perspectives.

## S12-P14

### Impacts of climate change on pelagic fishery resources in Chile

Eleuterio **Yáñez**<sup>1</sup>, Claudio Silva<sup>1</sup>, Luis Soto<sup>2</sup>, Jaime Letelier<sup>3</sup>, María Ángela Barbieri<sup>4</sup>, Francisco Plaza<sup>3</sup>, Felipe Sánchez<sup>3</sup>, Antonio Aranís<sup>3</sup>, Claudio Bernal<sup>3</sup> and Gabriela Böhm<sup>3</sup>

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With the A2 and 4×CO<sub>2</sub> scenarios of the IPCC, the estimated changes in sea surface temperature for the anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) fishing zone, and for the more oceanic fishing area for jack mackerel (*Trachurus murphyi*), showed an increase of 0.58°C - 1.59°C and 0.62°C - 2.51°C for both fishing zones until 2065, respectively. With scenario A2 and three values of fishing effort (current, +50%, -50%), landings of anchovy and common sardine would decrease, and landings of jack mackerel would increase slightly. On the other hand, with the 4×CO<sub>2</sub> scenario and the three values the fishing effort (current, +50%, -50%), increases in the landings of jack mackerel are estimated. This is probably due to a distribution further south and closer to the coast of the horse mackerel. This change in distribution would also be observed in the swordfish (*Xiphias gladius*). Finally, it is estimated that climate change would affect the habitat of resources.

Key words: Chilean coast, pelagic fisheries, climate change, impacts, habitat

## **S13: Multiple stressors at multiple scales: ecosystem based management in the face of changing ocean conditions**

### **S13-P1**

#### **Developing pelagic biodiversity indicators for ecosystem-based management**

Abigail **McQuatters-Gollop**<sup>1</sup>, Angus Atkinson<sup>2</sup>, Jacob Bedford<sup>1</sup>, Mike Best<sup>3</sup>, Eileen Bresnan<sup>4</sup>, Kathryn Cook<sup>4</sup>, Michelle Devlin<sup>5</sup>, Richard Gowen<sup>6</sup>, David G. Johns<sup>7</sup>, Clare Ostle<sup>7</sup>, Cordula Scherer<sup>8</sup> and Paul Tett<sup>6</sup>

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Europe is implementing ecosystem-based management (EBM) of its seas. The Marine Strategy Framework Directive (MSFD) is instrumental to delivering EBM, and requires that European marine habitats and species achieve Good Environmental Status for their biodiversity and food webs. The Plankton Index, a trait-based, indicator of change in plankton functional groups, allows the use of plankton data from multiple monitoring surveys with disparate methods of sample collection and plankton identification. Because the Plankton Index (PI) is based on time-series datasets, changes in the PI reflect multiple stressors on pelagic communities across spatial and temporal scales, such as natural variability, temperature increases, and changes in nutrient concentrations. The challenge, however, lies in separating these signals so that change in the PI can most effectively inform management measures. The first regional application of this approach in Northeast Atlantic (OSPAR) waters revealed that plankton communities underwent broad spatially-consistent, but significant, changes in plankton functional groups during the past decade. These results directly informed national and regional management efforts towards ecosystem-based management through an integrated assessment for the Northeast Atlantic. Assessing pelagic biodiversity change using a common indicator at the Northeast Atlantic scale for the first time is a significant step towards quantitatively evaluating Good Environmental Status for regional seas.

### **S13-P2**

#### **Response of phytoplankton functional groups to multiple simultaneous environmental stressors in the South China Sea**

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In this study, using a combination of complementary statistical methods, an attempt is made analysis the effects of simultaneous changes in nutrients (nitrate, phosphate, silicate and iron), temperature (SST), light (PAR), salinity, river discharge, mixed layer depth (MLD), and upwelling, on four broad phytoplankton functional groups in the South China Sea, during the decade 1998-2007. The overarching goal of this study is to develop a framework for understanding the response of Diatom, Coccolithophore, Chlorophyte and Cyanobacteria to multiple environmental stressors. The results reveal that positive changes in nitrate concentrations, fresh water and temperature (enhanced stratification) have strong positive influences on Diatom, implying a potential for increasing dominance of diatom in nitrogen-enriched eutrophic waters. Changes in nitrate concentrations and salinity have a significant negative effect, whereas changes in MLD have a significant positive influence on Cyanobacteria. Chlorophytes are significantly positively influenced by nitrate levels and negatively influenced by light availability. Changes in iron, silicate, phosphate and MLD have a strong positive influence whereas changes in SST have a strong negative effect on Coccolithophore. Overall, Chlorophyll-a concentrations (proxy of gross primary production) are largely negatively influenced by PAR and SST and positively influenced by MLD. Upwelling dynamics across multiple zones (off S.W Taiwan, Hanoi, Guangdong and Fujian) also influences the different phytoplankton communities in complex and unique ways. This study presents the synergistic effects of multiple environmental conditions on marine algae under complex oceanographic changes, and especially highlights the relatively strong impact of recent changes in SST and light. These results have important potential implications for the development of models of phytoplankton acclimation to multiple stressors, towards the design of effective marine Ecosystem Based Management strategies for the South China Marginal Seas.

### S13-P3

#### Sensitivity of California Current species to ocean acidification and climate change

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A challenge for marine resource managers is determining how species sensitivity to ocean acidification (OA) and climate change will affect marine ecosystems and their services. We study the sensitivity of economically and ecologically important species to OA and climate change in laboratory experiments and have developed meta-analysis techniques for estimating species sensitivity to OA, valuable input for ecosystem modeling efforts including those that consider multiple stressors. Our studies on Dungeness crab (*Metacarcinus magister*), the species which supports the most economically valuable fishery on the US West Coast, have demonstrated that zoea have a lower survival and slower developmental rate when reared in low pH (high CO<sub>2</sub>) treatments. However, temperature and dissolved oxygen seem to have a greater influence than pH treatments on survival, development, and growth in a number of early life stages. Our studies on Pacific krill (*Euphausia pacifica*), done in collaboration with University of Washington scientists, found that larval development and survival are reduced in low pH treatments. We are extending this work to better understand how OA, deoxygenation, and warming may affect adult krill survival, size, and body composition. Using databases of published research on species sensitivity to OA, we have identified the functional groups in the California Current Ecosystem that are most sensitive to OA (benthic herbivorous grazers, mesozooplankton, bivalves), input used in a recent regional ecosystem modeling effort. We have also found that mineralogy is a poor indicator of species sensitivity to OA and that summarizing information at high taxonomic levels may overestimate OA sensitivity.

### S13-P4

#### How does scientific research support management of marine social-ecological systems prone to tipping points? A systematic review

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Marine social-ecological systems (SES) are vulnerable to regime shifts, triggered at multiple scales by a combination of anthropogenic stressors, *e.g.* climate change, overfishing. These abrupt and unexpected changes threaten living marine resource populations and their sustainable exploitation with adverse social and economic consequences for human communities. In the face of the rapidly changing climatic conditions, regime shifts frequency is expected to increase. However, the respective non-linear dynamics and associated concepts of critical transitions need yet to be effectively integrated in holistic management approaches. Similarly, relevance of regime shift scientific research to ecosystem-based management of marine SES may be questioned. Following systematic review guidelines, we conducted a comprehensive search for literature published since 1990 in three multidisciplinary databases (Web of Science, Science Direct and Google Scholar). We retrieved 647 abstracts which were screened, checked for relevance and categorized. Relevance to marine SES management was evaluated by investigating the studies objectives, *e.g.* development of new tools and technics; understanding of mechanisms and drivers; providing managers with evidence for decision support; integration in holistic approaches such as integrative ecosystem assessment (IEA). Furthermore, natural language processing technics such as latent Dirichlet allocation or topic modeling, were applied to identify emerging topics and research gaps and gain insights on current research. Our synthesis on recent advances (and current gaps) in supporting management of marine SES prone to tipping points is particularly informative to researchers (and funders) aiming to support an integrative and efficient management of our marine resources in the context of climate change.



### S13-P5

#### Competing physical processes mediating climatic impacts on shelf sea ecosystems around the world

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Much is still unknown about the physical processes mediating the impact of climate change on shelf seas around the world through atmospheric, oceanic and terrestrial vectors. Particularly, if a shallow sea mixes through its whole depth seasonally, the common open-ocean climatic impact of reduced primary production due to increased permanent stratification simply no longer applies. Instead, the impact of climate change emerges from multiple, regionally specific interactions. For example, enhanced oceanic stratification can decouple currents from topographic steering, reducing ocean-shelf exchange. This in turn can lead to shelf seas becoming more riverine with a substantially enhanced risk of coastal eutrophication, but also mitigates the loss of oceanic nutrients. Here, we use global (NEMO-MEDUSA) and regional (NEMO-EREM) downscaled models to explore the contrasting physical processes driving ecosystem change. A single CMIP5 scenario to 2100 provides a consistent forcing set for these models, while statistical approaches provide uncertainty estimates. We focus on the NW European continental shelf, South China Sea/Gulf of Thailand and the equatorial East African Coast. We consider primary production, nutrients and oxygen as key intermediate ecosystem services driven by changes in atmospheric forcing, seasonal stratification, currents and heating hot-spots. We aim to develop simple conceptual models that identify the sign of the pressure-state response of the ecosystem, with confidence estimates, to help inform coastal management planning. We look for common patterns in these to build this into a widely applicable a pressure-state typology for climatic change at a regional to local scale (*e.g.* Holt *et al* 2016 doi:10.1016/j.pocean.2015.11.004).

### S13-P6

#### Lanthanum-exposure influences trace element accumulation, elimination, and oxidative stress in glass eels under a warming scenario

Cátia **Figueiredo**<sup>1, 2, 3</sup>, Tiago F. Grilo<sup>1</sup>, Clara Lopes<sup>2</sup>, Pedro Brito<sup>2, 4</sup>, Mário Diniz<sup>3</sup>, Miguel Caetano<sup>2, 4</sup>, Rui Rosa<sup>1</sup> and Joana Raimundo<sup>2, 4</sup>

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Rare Earth Elements (REEs) are receiving increasing attention, as they are essential for numerous high-technology products. Transfer to aquatic ecosystems is expected to increase, however little information is known about their impacts in aquatic biota and interactions with heavy metals, such as Cadmium (Cd), a known common toxic non-essential element. The major aim of this study was to evaluate the eventual interference of La, one of the most abundant REEs, on Cd accumulation and elimination and subsequent quantification of antioxidant enzymatic machinery, under climate change (CC). Considering the endangered conservation status of the European eel (*Anguilla anguilla*), we exposed glass eels via water to 0.5 µg.L<sup>-1</sup> of Cd for 8 days, after 4 days 120 ng.L<sup>-1</sup> of La was added, for extra four days. Afterwards, glass eels were left for 7 days in clean water to evaluate potential elimination of Cd and La. Exposure was performed under a warming scenario (Δ4°C). The results revealed that, under a warming scenario, La tend to block the accumulation of Cd. Accumulation of La was tissue-dependent and greater under CC. Oxidative stress and lipid damage occurred, with alterations in acetylcholinesterase and malondialdehyde levels and increased superoxide dismutase, catalase and glutathione-S-transferase activities, being enhanced under CC, indicating physiological stress. Glass eels were not able to eliminate efficiently La, which raises serious concerns, as adverse effects might become more pronounced for eels, after spending several years in future contaminated and warmer waters. This may represent a dangerous threat to species sustainability and conservation policies.

### S13-P7

#### Evidence of cue perception disruption in the European glass eel (*Anguilla anguilla*) migration under climate change

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Among catadromous species, the European eel (*Anguilla anguilla*) is a valuable fishery resource of high ecological and economical relevance, reflecting quite well the environmental health and integrity of aquatic systems, from freshwater to the open sea. Predicted changes in Earth's climate may influence the success of eels' migration to freshwater basins by interfering with optimal migratory temperature and sensorial ecology. In this study it was evaluated river-linked cue reception (lower salinity and geosmin, a substance of distinct earthy flavour and aroma) and how ocean warming ( $\Delta T = 4\text{ }^{\circ}\text{C}$ ) and acidification ( $\Delta p\text{CO}_2 = 500\text{ }\mu\text{atm}$ ) may affect eel migratory behaviour. Organisms were maintained for 60 days under salinity 35, to simulate climate change firstly to ocean conditions, and subsequently upstream the river, through a series of salinity gradients. Using a choice chamber with two Kitasato containers, we measured responsiveness to cues, as well as correct decision-making in groups of 10-15 individuals. Eels showed attractive response to stimuli provided to simulate riverward migration (geosmin and lower salinity levels), most evident under warming. Warming also increased the stimulus for counter-flux migration, even though precipitating wrong choices. Survival was lower in the warming treatments, while acidification showed a disruptive effect in stimuli sensorial capacity. Metabolic overdrive promoted by higher temperatures and  $\text{CO}_2$ -linked odour reception impairment reduced sensorial capability and overall organism fitness, eliciting profound effects on migratory behaviour. This may raise serious concerns for eels' population sustainability and overall fisheries resources.

### S13-P8 (CANCELLED)

#### Game theory applications to Baltic Sea Multispecies and Multi-fleet fisheries under climate variability

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Game theory has been an effective tool to generate solutions for decision making in shared fisheries. In the Baltic Sea, Baltic cod, herring and sprat fisheries are the backbone of the Baltic Sea fisheries that is under threat of climate change. Applications of game theory based on a food web model have not been studied before and the present study aims to fill this gap in the literature. In this study, we combine dynamic interacting multispecies ecosystem model called BALMAR with cooperative and non-cooperative approaches. Second, the study focuses on the effects of climate variability on the biological, harvest and economic output of the cooperative and the non-cooperative models by examining two temperature and salinity scenarios in addition to the base scenario without climate change. Third, the study analyses the stability of the cooperation and the non-cooperation behaviours and how they have been impacted by the change in climatic variables, temperature and salinity. Lastly, our study assesses the economic sensitivity of the models by different discount rates, cost and price parameters. Our findings would be useful in decision making processes of Baltic fisheries management under future climate change.

**Keywords:** Baltic Cod, Herring, Sprat, Baltic Sea, Bio-economic modelling, Game Theory, Climate change, Food Web Model

### S13-P9

## Development of guidance for integrating climate change Information into NOAA Fisheries Habitat Conservation Division consultation processes in the U.S. Greater Atlantic Region

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Numerous scientific publications and major national and international assessments have documented the effects of climate change on marine, estuarine, and riverine species and habitats. These impacts will increasingly affect the nation's ability to maintain productive and resilient ecosystems. Various federal mandates, including the Magnuson-Stevens Fishery Conservation and Management Act, require NOAA Fisheries' Habitat Conservation Division (HCD) to engage in consultations and provide advice intended to avoid and minimize adverse effects on fishery resources for actions proposed by federal and state agencies. I have developed guidance for integrating climate science into the HCD consultation program in the Greater Atlantic Region. This guidance includes: 1) a strategy and process for integrating climate change information in the HCD consultation program, 2) a synthesis of the science on global and regional climate change and the effects on marine, estuarine, and riverine species and habitats and, 3) a compilation of existing resources and tools (*e.g.*, links to reports, studies, and climate projection models) to assist HCD staff in identifying and communicating to federal and state agencies the climate-related impacts that may result from their actions. This guidance will also assist HCD staff in articulating the benefits of protecting coastal habitats, including climate resiliency and adaptation, and climate mitigation (*e.g.*, blue carbon). Further, this guidance supports NOAA's mission to conserve and manage coastal and marine ecosystems and resources, protect and restore habitats and ecosystems, and communicate the effects of climate change on coastal resources to federal and state agencies, and the public.

### S13-P10

## Approaches to utilizing indicators to improve understanding of climate change in the Pacific Islands

Seema **Balwani**<sup>1</sup>, John J. Marra<sup>1</sup>, Jamison Gove<sup>2</sup>, Thomas Oliver<sup>2</sup> and Phoebe Woodworth-Jefcoats<sup>2</sup>

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The impacts of climate change pose an existential threat to the Pacific Islands. Increasing sea surface temperatures, rising sea levels, coral bleaching and ocean acidification are examples of changes that are already impacting the lives and livelihoods of the people in the region. However, communicating the range of these threats can often be challenging, due to the interdisciplinary and complex nature of the science, and the uncertainties associated with future projections. Climate indicators are useful tools in offering a common language to provide local communities with a baseline understanding of key climate parameters, and demonstrate the level of changes in these parameters over time. This presentation will examine three different types of indicators and describe their utility across multiple spatial scales. The first set of ecosystem indicators monitor general climate parameters at a large spatial scale over an extended time period. The second focuses on the topic of fisheries, and demonstrates how indicators are used to provide the fishing community with specific knowledge directed at their industry. The third focuses on a specific geographic region, West Hawai'i on the island of Hawai'i, where climate indicators are part of an Integrated Ecosystem Assessment. We will compare and contrast these indicators to show how similar parameters are used for varying management purposes: 1) to track on long term environmental change over a broad geographic area; 2) to track short- and long-term change across multiple areas for a particular sector; and 3) to track short- and long-term change for a specific geography.

## S13-P11

### Ecosystem-level biological reference points under varying climate and ecosystem states

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While single-species-based stock assessment models produce estimates of recruitment and natural mortality over time, these models cannot capture the causes of the annual variability in these important productivity parameters. Biological reference points (BRPs) derived within these models are void of consideration for environmental changes, which render greater uncertainties in forward projection of population dynamics needed for management decision-making in the context of climate change. Ecosystem models on the other hand are valuable tools for advancing the understanding of processes, including physical-biological interactions and predator-prey trophic relationships, and their impacts on fishery resources, due to their ability to incorporate physical drivers and simulate spatial dynamics of trophic interactions. In this study, we use an end-to-end model (OSMOSE, Object-oriented Simulator of Marine Ecosystems) for the marine ecosystem off western Canada to develop ecosystem-level BRPs for four key species including Pacific Herring (*Clupea pallasii*), Pacific Cod (*Gadus macrocephalus*), Lingcod (*Ophiodon elongates*), and Walleye Pollock (*Theragra chalcogramma*) under three distinct periods (pre-1977, 1977-1997, post-1997), and across the entire modelled period from 1951-2017 (representing a historical average condition). We also develop ecosystem-level BRPs under three hypothetical periods after 2017 representing cold and warm extremes as well as a projected mean condition. These ecosystem-level BRPs complement single-species stock assessments by identifying key dynamics and ecosystem properties that impact multiple species and fisheries over the long term, thus providing stock assessment scientists and resource managers with basis for better incorporation of ecosystem considerations into scientific advice for sustainable fisheries management that account for uncertainty in productivity.

## S13-P12

### A dynamic ocean management approach to reduce bycatch in the California Drift Gillnet fishery

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Managing for economic and ecological sustainability in marine fisheries often requires novel approaches. Traditional spatial management approaches use large-scale seasonal closures to avoid bycatch, but *dynamic ocean management* provides alignment between management areas and ocean features in space and time. Such targeted approaches can use mechanistic or statistical models of how distribution and likelihood of catch and bycatch varies with the oceanic environment. Here we explore the California Drift Gillnet fishery that targets swordfish, thresher shark, and mako shark, but also catches a number of species as bycatch including but not limited to sea lions, sea turtles, and blue sharks. This tool uses habitat models and risk weightings to estimate patterns of catch and bycatch as a function of management concern in near time. Anomalous ocean conditions such as recent marine heatwaves can change species distribution patterns, thus we can use this tool to examine how predicted patterns in catch and bycatch change. Dynamic ocean management approaches could be applied to other migratory species for which data are available, and our example emphasizes the utility in integrating multiple data types for marine conservation and management.

### S13-P13

#### Effects of climate and demographic change on spawn timing

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Shifts in phenology are a well-documented ecological response to changing climate, which may or may not be adaptive for a species depending on the climate-sensitivity of other ecosystem processes. Furthermore, phenology may be affected by factors in addition to climate, which may accentuate or dampen climate-driven phenological responses. In this study, we illustrate how climate change and fishing (via effects on population demographic structure) jointly affect spawning phenology in a fish species of major commercial importance: walleye pollock (*Gadus chalcogrammus*). We use 30+ years of data from larval surveys to reconstruct timing of pollock spawning in the Gulf of Alaska, and find that the mean date of spawning has varied by three weeks over the last three decades. Climate clearly drives variation in spawn timing, with warmer temperatures leading to earlier spawning. However, population demographics were equally important: an older spawning stock tended to spawn earlier and over a longer duration than a younger stock. In pollock, and many fishes, spawn timing determines the potential for match (or mis-match) of larval offspring with prey, as well as the size obtained prior to the first winter, when size-dependent mortality may be acute, both processes important for determining year-class strength. We conclude by illustrating how the ecological consequences of future climate-driven shifts in phenology may be mediated or accentuated by changes in fishing pressure.

### S13-P14

#### Fishing and temperature effects on the size structure of exploited fish stocks

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Size structure of fish stock plays an important role in maintaining sustainability of the population. Size distribution of an exploited stock is predicted to shift toward small individuals caused by size-selective fishing and/or warming; however, their relative contribution remains relatively unexplored. In addition, existing analyses on size structure have focused on univariate size-based indicators (SBIs), such as mean length, evenness of size classes, or the upper 95-percentile of the length frequency distribution; these approaches may not capture full information of size structure. To bridge the gap, we used the variation partitioning approach to examine how the size structure (composition of size classes) responded to fishing, warming and the interaction. We analyzed 27 exploited stocks in the West US, Alaska and North Sea. Our result shows fishing has the most prominent effect on the size structure of the exploited stocks. Also, variation partitioning outperforms the univariate SBIs in detecting fishing effects. We found that the fish stocks experienced higher fishing pressure is more responsive to temperature effect in their size structure, suggesting that fishing may elevate the sensitivity of exploited stocks in responding to environmental effects.

## S13-P15

### Validating the performance of zooplankton as ecological state indicators - A European comparison

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Zooplankton is the central trophic level in marine ecosystems and hence crucial for food web functioning and productivity. It reproduces fast and reacts rapidly to environmental signals such as those caused by climate change, e.g. warming, acidification and deoxygenation. Hence, zooplankton has an undeniable potential to serve as indicators for ecosystem-based management. However, the utility and robustness of zooplankton indicators has not been sufficiently tested. Here, we present a suitability study across three European Seas in which we evaluate and compare the performance of different zooplankton metrics as ecosystem state indicators for management. The assessment is based on *INDperform*, a new R package that implements a comprehensive quantitative framework for selecting and validating the performance of state indicators. The package offers functions to identify temporal indicator changes, model relationships to pressures and to quantify the robustness of these models. Based on these analyses and a scoring scheme for selected criteria, the individual indicator's performances are quantified and visualized. An implemented cluster analysis based on indicator scores is further used to select complementary indicators that perform well. Our comparison sheds light on spatial differences in zooplankton indicator performances with respect to direct and indirect pressures and the role of non-linearity and non-additivity in their pressure responses. We advocate the use of *INDperform* as decision-support tool for selecting suites of complementary indicators under management schemes such as the EU Marine Strategy Framework Directive.

**Keywords:** zooplankton, state indicators, performance validation framework, R package *INDperform*, European comparison

## **S14: Vulnerability and adaptation of marine socio-ecological systems to climate change**

### **S14-P1**

#### **Socio-economic impacts of climate change on coastal fishing communities in the Eastern US: Risk assessment and visualization**

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Coastal fishing communities are exposed to the dynamic interface between the land and the sea. Many of these communities evolved through dependency on marine resources to satisfy social, cultural and economic needs. Living in close proximity to coastal waters offers increased access to fishing grounds and aesthetically desirable natural amenities. But this proximity also poses increased risks of vulnerability to coastal hazards such as sea level rise and storm surge. These risks may also be exacerbated by changes in fishery management regimes. We sought to understand the scope of potential impacts of climate change on coastal communities. To assess the risk of these coastal hazards, six sea level rise shapefiles and four coastal storm surge layers were overlaid separately with community boundaries. A Sea Level Rise Risk Index and a Storm Surge Risk Index were developed using the area within a community affected by these events for nearly 3,000 communities in the Eastern U.S. To estimate direct economic impacts of these coastal hazards on communities, business location data were overlaid separately with sea level rise and storm surge layers to identify businesses that might be affected. The focus has been on seafood commerce businesses including seafood processors, seafood markets and seafood wholesalers. Revenue affected by sea level rise and storm surge events was also evaluated. Our findings demonstrate the linkages between physical, human, and economic dimensions of community vulnerability, which will provide useful information for the decision-making process in relation to fisheries management, climate adaptation and risk mitigation.

### **S14-P2**

#### **Dry Tortugas National Park: Developing a fishery dependent survey as an indicator of marine protected area success**

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In 2007, Dry Tortugas National Park created a Marine Protected Area (MPA) in 46% of its area as a management tool to protect natural resources. MPAs have previously been shown to be successful in increasing fisheries (Roberts 2010), and MPAs are an ocean ecosystems management technique that is not susceptible to the impacts of climate change. The park's 5-year science plan called for the development and implementation of a fisheries dependent survey system to evaluate the status of the Dry Tortugas fisheries. This study developed, implemented and analyzed a pilot creel survey system to gauge the status of the recreational fisheries and the effect to the created MPA. By analyzing target species CPUE, overall CPUE, population length distribution, recreational angling in and outside the park and boating activity, it was determined that with an overall CPUE of 3.07, the fisheries in the park are healthy and that the MPA has beneficial effects. It was also determined that a fisheries dependent survey is an efficient and economical tool to evaluate MPA effect on fisheries and the method could be applied to similar areas. This method will be continued in the future in Dry Tortugas National Park to allow for long term analyses.

### S14-P3

#### **Climate change and marine recreational fishing in Europe: Potential benefits and challenges**

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Marine recreational fishing is important in Europe in terms of benefits to deprived coastal economies and people's wellbeing, and it is a large component of total fish landings for some species. Climate change is anticipated to affect recreational fishing in a number of ways, creating both opportunities and challenges. Physical changes to the marine environment are expected to impact availability of fish to recreational fishers, through effects on recruitment, growth, and survival. There may also be distribution shifts of fish stocks which will impact the target species of recreational fishers. Climate change could affect the safety and desirability of fishing, and the costs if gear is lost or damaged in bad weather, or fishers have to travel further for their preferred species. In addition, changing marine conditions may affect the catchability of fish. However, not all effects are expected to be negative. In some cases, weather conditions may improve and species' shifts could bring desirable species to new areas, such as increases in sea bass or tuna numbers in northern Europe. Here, we discuss how these changes may have implications for stock management boundaries in Europe, the behaviour of recreational fishers and the potential development opportunities for local economies in response.

### S14-P4

#### **Local ecological knowledge in managed fisheries: A Maine case study**

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Maine's commercial fishing sector has a collective body of local ecological knowledge (LEK) that is high-resolution, temporally continuous, and place-based, and can meaningfully contribute to fisheries science and management. However, the distribution of fishermen's knowledge is often spatially patchy and constrained by the institutional arrangements that shape individual interactions with the environment. We explore this tension through research on LEK in the eastern Gulf of Maine, working toward a theoretical middle ground that is sensitive to the uneven nature of fishermen's knowledge while simultaneously recognizing its immense value. Through semi-structured interviews with commercial fishermen, we use a network approach to map the ecosystem structure and dynamics described by fishermen. These interviews have provided insight into local fluctuations in water temperature and weather patterns, predator prey dynamics, and the complex interactions between fisheries and their habitat. The continuous and historical nature of this knowledge makes it particularly useful for understanding both long-term trends and system response to change. We find evidence of a significant positive relationship ( $p < 0.01$ ) between diversified participation in fisheries and the production of ecological knowledge. Namely, fishermen who participate or have participated in multiple fisheries seem to develop a more holistic understanding of the marine environment and its dynamics because of regular interactions with different components of the system. This has important implications for both the kinds of information fishermen can contribute to ecosystem science, and the capacity of those fishermen to engage in the management of a complex and multi-scalar ecosystem.



## S14-P5

### Social-ecological vulnerability of Northeast U. S. fishing communities to climate change

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Climate change is affecting marine ecosystems, fish populations, fisheries, and fishing communities around the world. Understanding local community vulnerability to large-scale climate-driven species changes is a critical step towards supporting forward-looking planning and adaptation. Vulnerability at a community scale is a function of future changes in species availability, the nature of current resource use and dependence, and local adaptive capacity. We bring these sources of variability together across more than 100 Northeast U. S. fishing communities from Maine to Virginia to assess their coupled social-ecological vulnerability under future climate scenarios. Results of this assessment provide insights not only into relative vulnerability among communities, but also into key drivers of the ultimate vulnerability rating within communities, which can be used to highlight key risks to specific ports. More broadly, the assessment process generates information on species that are expected to increase in fishing areas used by certain communities, which provides insights into potential future opportunities. Outputs of the vulnerability assessment provide a basis for more in-depth work in a subset of communities to identify adaptation strategies of interest, evaluate those strategies using bioeconomic models, and provide information that can be used to support decision-making and adaptation planning at community and regional levels.

## S14-P6

### Spatial planning of marine aquaculture under climate variability and change: A case study for mussel, finfish and kelp farms in California

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The growth of marine aquaculture over the 21<sup>st</sup> century is a promising venture for food security because of its potential to fulfill the seafood deficit in the future. However, to maximize the use of marine space and its resources, the spatial planning of marine aquaculture needs to consider the regimes of climate variability in the oceanic environment, which are characterized by large-amplitude interannual to decadal fluctuations. It is common to see aquaculture spatial planning schemes that do not take variability into consideration. This might be a problem for management and for the expansion of marine aquaculture, because projects require investments of capital and need to be profitable to establish and thrive. We analyze the effect of climate variability on the profitability of three aquaculture systems (mussels, finfish and kelp) being planned for the Southern California Bight. Using historical environmental data to feed climate sensitive production models, we estimate the Net Present Value as an economic indicator of profitability. We then use Principal Component Analysis and Empirical Orthogonal Functions to link productivity of these farms with the climate of the North Pacific Basin. We find that variability has a strong impact on profitability both temporally and spatially, and that production of species that depend on ocean nutrients follow decadal regimes of Pacific climate while temperature sensitive species (finfish) follow more closely interannual variability. These results suggest that managers and investors would benefit from explicitly including climate variability when making decisions on where, when and what to cultivate to maximize profitability. Finally, the response of the farms to climate variability is used to quantify a sensitivity matrix to the environmental drivers that is used to project the impact of climate change scenarios on profitability.

## S14-P7

### **Development of a vulnerability assessment for climate effects on the habitats of living marine resources**

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Vulnerability assessments have become an important tool in climate change science. In the United States, NOAA Fisheries has developed a framework for assessing the vulnerability of marine fish and invertebrate species in a changing climate. This framework has been linked to social vulnerability of human communities through the vulnerability of fisheries. A similar framework is under development for assessing the vulnerability of marine mammals and sea turtles. These vulnerability assessments support fisheries and protected species management in freshwater, coastal, and marine ecosystems and contribute to: i) an understanding of the long-term effects of climate change, ii) the identification of particularly vulnerable species, iii) decisions regarding the allocation of effort and resources, and iv) discussions of adaptation measures for specific species or groups of species. NOAA Fisheries is also responsible for conserving habitats that support fishery and protected species. Here we describe the development of a climate vulnerability assessment framework to consider climate impacts on habitats in the Northeast U.S. region. The regional focus allows the development of a practical application, as well as provides a basis for potential use in other regions. We will review existing habitat-related vulnerability assessments and describe the requirements of a NOAA Fisheries habitat climate vulnerability assessment. We will then discuss the framework developed for the Northeast region and describe next steps in implementation of the methodology.

## S14-P8

### **Analysis on the harm and potential risk of aquaculture in Taiwan under the extreme climate disaster**

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In recent years, the aquaculture fisheries have gradually become an important industry and a key role in the seafood supply and demand. Since 2011, the quantity of aquaculture has been maintained at about 310,000 tons with an annual value of about 400 hundred million NT in Taiwan. The main aquaculture species is include milkfish, tilapia, clams and oysters etc. However, aquaculture is closely linked natural environment. It's easy to result in disaster when typhoon or torrential rain occurs. Lead to deterioration of water quality, loss of aquaculture creatures, even though the fish ponds were buried and the dike was collapsed by the mud, resulting in the loss of fish famers. Ultimately, the extreme meteorology caused by the extreme climate will directly or indirectly affects to the aquaculture in Taiwan. In order to understand the effects and impacts of aquaculture fisheries under the CC, we are implemented implement the program of Taiwan Climate Change Projection and Information Platform (TCCIP). In the study, we are analyzed the long-term changes of aquaculture geographical location, area, yield and dominant species in Taiwan from 2000 to 2017. And, we are elected the temperature as the climate factor to explore the impact of historical extreme climate disasters on aquaculture fisheries and determine the extent of harm, vulnerability and potential risks in the current aquaculture areas under the climate change. And, when face to the more extreme meteorology event, coming up with relevant measures and methods.

## S14-P9

### The role of governance in adaptation of fisheries to climate change

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Governance affects the degree to which fisheries adapt to climate change. Many, if not most, fish populations are now understood to occur as hierarchic metapopulations organized around fine-scale oceanographic features. Climate impacts occur as changing conditions affect subpopulations at the base of such hierarchies. Most fisheries are prosecuted and managed at scales much larger than that at which climate impacts first become evident. Co-management, a form of governance in which authority for management is shared between government and fishermen, has been demonstrated to help match management strategies to the fine-scale dynamics that cumulatively drive fisheries outcomes at the metapopulation level. Co-managed fisheries are likely to detect climate impacts at an earlier stage than those managed at a larger scale; however, it is unclear if they are more successful in adapting to such impacts than more traditional systems of governance and management. Climate impacts are evident in fisheries in the Gulf of Maine, a semi-enclosed sea in the northwest Atlantic that is warming faster than 99% of the world's oceans and is subject to sea level rise and acidification. Fisheries in the Gulf of Maine, including for lobster and cod, are analyzed for the potential role that governance plays in adaptation to climate impacts. The analysis considers the history and status of these fisheries, efforts to implement an ecosystem-based approach to fisheries management, and the resilience of governance to climate impacts.

## S14-P10 (ALSO TALK, June 8, 14:00, p. 165)

### Marine climate-changes tropical blindspot

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Contrary to popular perception, I propose that it is tropical waters, rather than polar waters, where the most concerning warming of the ocean is taking place. The species that live in these waters are particularly sensitive to warming, and while the human societies relying on them are amongst the world's most dependent on the ocean, they also have the least capacity to adapt. Yet, in spite of this important vulnerability, climate change impacts in tropical waters are severely understudied: just 2% of the relevant literature falls between the tropics. Closing this knowledge gap will require a concerted effort from funding agencies, the IPCC, individual scientists and the international community. Failing to do so may result in unexpected consequences for the populations of tropical nations that are dependent on the oceans.

## S14-P11

### Climate changes and overfishing threats to Western Baltic cod fishery

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Overfishing and global warming are threatening the sustainability of marine social-ecological systems (SES) worldwide. In this study, we focused on the particular case of Western Baltic cod fishery which has shown a decreasing trend over the last fifteen years inducing substantial social and economic consequences. To understand the conflicts arose by this situation, we reviewed current knowledge of the main components of Western Baltic SES, *i.e.* food-web, recreational and commercial fisheries, regulation and management, stock-recruitment dynamics, (and ultimately highlighted gaps in knowledge) and investigated their interactions. Finally, we investigated climate change, environmental changes and multiple management measures effects on the Western Baltic cod productivity and associated fishery. In addition to the valuable information this study provides to understand the threats to the sustainability of Western Baltic cod fishery, the results obtained allow a comprehensive understanding of this SES, necessary to assess cod fishery vulnerability, particularly under growing climatic and anthropogenic pressures. Finally, the study highlight needs and future directions to support a comprehensive management of the system and achieve a sustainable exploitation of Western Baltic cod stock.

## S14-P12

### **U.S. West Coast fishing communities and climate vulnerability in an ecosystem-based management context**

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As global developments in climate change and corresponding ocean shifts threaten U.S. fisheries with rapid, uncertain change, West Coast marine scientists and managers have newly emphasized ecosystem-based analysis and management. The development of the West Coast-specific California Current Integrated Ecosystem Assessment (CCIEA) has accordingly allowed for research on human communities to be included in this holistic endeavor, opening spaces for enhanced collaborations between applied social and biophysical scientists. These collaborations are beneficial, but challenges emerge within varying aspects of the integrated approach to ecosystem-based management including, for example, the natural science emphasis on annual monitoring of ecosystem indicators. Alongside limitations on available social data and other social data collection constraints that sometimes preclude such annual monitoring, the distinctiveness of social science methodologies requires new thinking on collaborations and socio-ecological ecosystem modeling efforts. One productive avenue for collaboration involves the linkage of climate vulnerability evaluations for marine species with evaluations of community social vulnerability. These linkages allow for integrated metrics of exposure and vulnerability for a range of people, places and marine species.

## S14-P13

### **Status of fish stock climate vulnerability assessments in U.S. large marine ecosystems**

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The impacts of climate change on marine ecosystems are becoming more apparent in fisheries across the world. However, not all fish stocks are responding to these changes in the same ways or at the same rates. Changes in the natural variability of fisheries are becoming less predictable based on historical trends. In response to this change and to better predict the impacts of changing climate on managed species, climate vulnerability assessments have emerged as a useful tool to provide a general understanding of the relative response of fish stocks to a number of climate related exposure variables. We have developed a climate vulnerability assessment for marine fish and shellfish species using metrics related to sensitivity and exposure scored by panels of regional experts, which has been implemented across federally managed fish stocks in several large marine ecosystems in the U.S. We provide an overview of the status of these assessments and compare the findings across regions to identify overarching themes, key drivers of vulnerability, and lessons learned. We will also demonstrate how these results are being used to prioritize scientific research projects and how they are incorporated into fisheries management decisions.

## S14-P14

### Evaluating climate driven changes in spatial distributions and predator-prey overlap in the Alaskan groundfish fishery

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Alaska's groundfish fishery is the largest fishery by volume in the United States and plays a substantial role in the region's economy. Because of its commercial importance and the vulnerability of the region to climate change, we used the fishery as a case study to examine how warming will affect the distribution of individual species and spatial overlap among predator and prey. Relatively few studies have assessed how climate change will affect community structure, even though species interactions have been identified as a key factor for improving projections of habitat suitability under climate change. Our study included three commercially and ecologically important predators and their prey in the Eastern Bering Sea and the Gulf of Alaska. We built species-specific habitat models using NMFS bottom trawl survey data (1982-2016) to determine species' preferred temperature, depth, and substrate type. We used the models to project habitat suitability under both historic and future conditions and then calculated change in biomass, distribution, and spatial overlap for each predator/prey relationship by 2055. Preliminary results indicate that certain predator/prey links have different bottom temperature preferences; for example, arrowtooth flounder (*Atheresthes stomas*) prefers warmer temperatures than their prey, Alaska Pollock (*Hippoglossus stenolepis*), which resulted in increased spatial overlap during warm periods. The results of this study improve our understanding of how climate change influences ecosystem restructuring and inform management agencies of potential distribution and biomass changes in a vital fishery.

## S14-P15

### Ecuador: Integrating disaster risk reduction and climate change on the coastal zone

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Ecuador have changed the legal framework in 2008 to further the development of policies for Climate Change Adaptation and Mitigation (CCAM), and Disaster Risk Reduction (DRR) to reduce the impacts of climate variability and change by strengthening the inter-sectorial institutional coordination, increasing the capacity of local governments, and empowering communities along the coastal zone. In this study we analyzed various examples of the policy implementation on CCAM and DRR at local, regional, and national level. The impacts on the Ecuadorian coastal zone include a destructive wave regime causing coastal erosion, sea surface temperature changes affecting local fisheries, and flooding in coastal cities impacting the economy and livelihood of coastal population. The climate change agenda in the coastal zone, is aiming to increase the resilience of the ecosystems and communities by programs such as *Socio Manglar* and adaptation programs on the coastal range. At national level an Inter-institutional Climate Change Committee (ICC) developed the National Strategy for Climate Change that determined priority sectors, capacity building needs, and a framework to integrate mitigation and adaptation at municipal level. On the other hand, DRR policies are enforcing the relocation and retreat from risk prone area on touristic corridors and coastal municipalities. DRR and land planning are banning any development on high risk zones of storm surges and erosive coastal process. A municipality-funded program for DRR encouraged prevention upon response, supports infrastructure construction for coastal protection, and finally, inter-institutional arrangement allows integrative multi-hazard approaches that have increased the resilience of coastal communities in Ecuador.

**Key words:** Disaster risk reduction (DRR), adaptation, mitigation, resilience, inter-institutional, multihazard

## **S16: Climate, Oceans and Security**

### **S16-P1**

#### **Impact of climate change on Indian monsoon: Implication to cyclones in Bay of Bengal**

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Variability in the sea surface temperature and salinity are the certain parameters to be understood from the Indian Seas in order to understand Monsoon and other sea induced processes. Indian monsoon is not a local phenomenon but one of the major components of the global circulation. The Indian subcontinent is one of the worst affected regions in the world. The subcontinent with a long coastline of 8041 kilometres is exposed to nearly 10 per cent of the world's tropical cyclones. Of these, the majority of them have their initial genesis over the Bay of Bengal and strike the East coast of India. On an average, five to six tropical cyclones form every year, of which two or three could be severe. More cyclones occur in the Bay of Bengal than the Arabian Sea and the ratio is approximately 4:1. Cyclones occur frequently on both the coasts (the West coast - Arabian Sea; and the East coast - Bay of Bengal). An analysis of the frequency of cyclones on the East and West coasts of India between 1891 and 1990 shows that nearly 262 cyclones occurred (92 of these severe) in a 50 km wide strip above the East coast. Tropical cyclones occur in the months of May-June and October-November. Cyclones of severe intensity and frequency in the North Indian Ocean are bi-modal in character, with their primary peak in November and secondary peak in May. The disaster potential is particularly high during landfall in the North Indian Ocean (Bay of Bengal and the Arabian Sea) due to the accompanying destructive wind, storm surges and torrential rainfall. Of these, storm surges cause the most damage as sea water inundates low lying areas of coastal regions and causes heavy floods, erodes beaches and embankments, destroys vegetation and reduces soil fertility. Cyclones vary in diameter from 50 to 320 km but their effects dominate thousands of square kilometers of ocean surface and the lower atmosphere. The perimeter may measure 1,000 km but the powerhouse is located within the 100-km radius. Nearer the Eye, winds may hit at a speed of 320 km. Thus, tropical cyclones, characterized by destructive winds, torrential rainfall and storm surges disrupt normal life with the accompanying phenomena of floods due to the exceptional level of rainfall and storm surge inundation into inland areas. Cyclones are characterized by their devastating potential to damage structures, viz. houses; lifeline infrastructure-power and communication towers; hospitals; food storage facilities; roads, bridges and culverts; crops etc. Proper sophisticated cyclone forecasting facility and the security concern of the Coast guards are the need of the hour. Security issues for the property and the people is always at risk during the cyclones along the coasts. A protocol with structured template of safety and security is warranted in order to minimize the casualties and property risks. Further action has to be taken care for the checking up of coastal erosion as well. This paper attempts to understand the climate phenomena and processes in which the Indian Ocean-Bay of Bengal is, or appears to be, actively involved in the climate variability induced cyclones towards the Indian sub continent and its security impacts as well.

## S16-P2

### **Arctic coastal erosion: development of a mechanistic model designed for coastal hazards evaluation**

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Accelerating Arctic coastal erosion rates (now approaching 20 m/yr at erosional hotspots) have placed existing military detection and early warning infrastructure and multiple Alaska communities at imminent risk of destruction. Several coincident changes in the Arctic environment exacerbate the magnitudes and rates of coastal erosion along the Alaskan Coast: sea ice extent is declining (~40% decline since 1979), effective fetch and storm period are increasing wave power, ocean temperatures are warming (ice-albedo positive feedback), and permafrost is thawing, with the Arctic warming at twice the rate of the rest of the US. Although the permafrost coastlines comprise one-third of the global coastline length, current understanding of coastal landscape evolution driven by thermo-abrasive processes is simplified and insufficient to mechanistically describe storm-driven erosion events. In the thermo-abrasive process, the parent material at the base of the bluff is warmed by the ocean and eroded by the mechanical action of the ocean during storm events. Modeling this process requires critical hydrodynamic, thermal, and mechanical processes associated with the Arctic system be integrated. We hypothesize that a sequential coupling of an Earth system model, sea ice-ocean wave model, near-shore circulation model, permafrost thermal model, and permafrost bluff stress state model will facilitate the development of a process-based predictive model to inform Arctic stakeholders. This talk will detail a newly launched numerical modeling and validation campaign within the context of exploring impacts on new and existing infrastructure, cultural sites, and nearshore ecological stability.

## **S17: Effects of climate change on ocean ecosystem health: Projecting occurrences of harmful algal blooms and disease outbreaks and assessment of the risk to ecosystem functioning, aquaculture, fisheries and human health**

### **S17-P1**

#### **Seasonal forecasting of coral disease outbreak risk**

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NOAA Coral Reef Watch (CRW) has developed prototype seasonal forecasts of coral disease outbreak risk to support reef management. These complement corresponding near real-time satellite monitoring tools for disease outbreaks available for select coral reef regions since 2010 and CRW's global suite of satellite monitoring and modeled outlooks for bleaching heat stress. Satellite monitoring for disease risk applies existing relationships between outbreaks of tissue loss diseases and sea surface temperature (SST) metrics during winter (providing a post-winter risk assessment) and the subsequent summer (near real-time heat stress updates). The new coral disease seasonal forecasts augment post-winter risk assessments to provide reef managers and other stakeholders with advance warning of potential summer conditions conducive to outbreaks, enabling timely response to events. Like CRW's bleaching outlook, the disease forecast applies SST predictions from the Climate Forecast System Version 2 (CFSv2) produced by NOAA's National Centers for Environmental Prediction. Prototype disease forecasts have been developed for the Hawaiian archipelago and Great Barrier Reef, Australia, where satellite monitoring of disease risk is already implemented. Additional regions and disease types will be incorporated into both the seasonal forecast and satellite monitoring as further relationships are identified or confirmed between disease observations and temperature metrics. This work is part of the FORE-C project, "Forecasting coral disease outbreaks across the tropical Pacific Ocean using satellite-derived data", awarded by the NASA Research Opportunities in Space and Earth Science's 2016 Earth Science Applications: Ecological Forecasting program to the University of Hawai'i and NOAA.



## **S18: Coastal ecosystem and their blue carbon science, conservation and policy progress**

### **S18-P1**

#### **Land use and climate change impact on coastal ecosystem services in upper region of the Gulf of Thailand**

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The transition area between the land and sea creates many economic activities while maintaining different services of ecosystem by providing habitat, securing food resources and protecting disaster. Nowadays, impact of climate change on coastal area has been evidenced through intensification of altering climate patterns which will entail more frequent and intense precipitation, storm, erosion as well as sea level rise. However, it is critical not to lose sight of taking land use change impact into account when evaluating coastal vulnerability. This paper focuses on how to project future services of coastal ecosystem in two provinces of upper regions of the Gulf of Thailand. Climate in 2050 is projected by using WorldClim database. Three scenarios of land use namely; business as usual (BAU), rapid tourism development (RTD), and sustainable development (SD) are created by analyzing related driving forces with scenario based method. Result reveals a risk along with RTD and BAU scenarios due to tourism development, loss of mangrove forest and coastal erosion, while SD scenario tends to encourage coastal sustainability by halting of infrastructure development and increasing mangrove area. Results on climate projection show an increase in sea level, temperature and precipitation, with an associated decrease in mangrove cover will ultimately degrade the function and service of coastal ecosystem and community resilience. There is thus an urgent need on scaling up and restoring mangrove ecosystems in line with SD scenarios and promoting coastal sustainability by mainstreaming land use planning in future coastal development plan and policy.

### **S18-P2**

#### **IUCN's role in supporting ocean science and action for conservation in a changing climate**

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The International Union for the Conservation of Nature is the world's largest and most diverse environmental network. IUCN, jointly with its members and partners, is playing a key role in synthesizing ocean science to support marine management decisions, particularly the management of protected areas and threatened species. Through IUCN's World Commission on Protected Areas and IUCN's Global Marine and Polar Program, major scientific publications have been issued over the past five years on ocean warming, adapting to climate change, nature based solutions to climate change (including blue carbon and Ecosystem-based Adaptation), and the significance and management of natural carbon stores in the open ocean. Another report on the global impacts of oxygen deoxygenation is in development. This presentation will summarize some of the key findings from these landmark reports, highlight examples how this work shifted international (i.e UNFCCC) and national policy change and discuss the ways in which they are informing better coastal and ocean management as well as innovative finance decisions.

### S18-P3

#### **Anthropogenic blue carbon: Assessing the contribution of seaweed aquaculture for carbon uptake and storage**

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Blue carbon is a component of the pool of biological produced organic carbon that can be stored in a form that is relevant for climate mitigation. However quantification of the fate, export and potential sequestration of blue carbon is complex and poorly understood and constrained. Producers include mangroves, seagrasses and macroalgae resident in the coastal zone. Recent estimates suggest that macroalgae may be the largest global contributor to blue carbon. The production and fate of carbon that originates from the both naturally-occurring as well as managed (i.e. farmed) kelp beds and other macroalgal systems is rarely quantified. Modeled estimates are complicated by extensive physiological plasticity and adaptations of seaweed, specifically their ability to store organic carbon under nutrient limited and high light conditions. Thus models which use average carbon conversion factors will introduce large uncertainties in the estimates of carbon content. The mariculture of kelp and other seaweed are expanding with an annual global harvest of  $\sim 30 \times 10^6$  tonnes in 2015. Although wet weight of the seaweed harvest is relatively well quantified, the fate of the total biomass (harvested and unharvested particulate carbon and dissolved/exudated carbon) has not been assessed with respect to climate. As a result of the poorly constrained carbon conversion factors and gross biomass production, the potential for carbon capture and storage or the eventual sequestration is difficult to calculate. Here we examine the potential for seaweed aquaculture to capture and store carbon and identify the data gaps that need to be filled to adequately quantify this potential.

### S18-P4

#### **Coastal blue carbon stock in Southeast Asia: What does it mean to the region's climate change mitigation effort?**

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With the rapid economic expansion and integration in Southeast Asia, the region's primary energy consumption (2007-2030) will grow at 4.5% per annum resulting in a corresponding 5.7% increase in CO<sub>2</sub> emissions. Approaches currently in place to reduce emissions, however, are focused on application of high-carbon technology and resource subsidies which compound especially the financial problems of most member countries. One practical and cheaper solution is the development of blue carbon R and D and application of its outcome in the required CO<sub>2</sub> emission abatement to 2100, which also enhances the region's energy cooperation towards a low-carbon, blue economy. Mainstreaming blue carbon into regulatory frameworks in natural coastal resources management in Southeast Asia is a goal. Southeast Asia's 4.6 Million ha of mangroves potentially give the region 4.6 Billion Metric Tons Carbon locked in the plants and sediments. In parallel, the region's 11.4 Million ha seagrass beds potentially give the region 139 Billion Metric Tons Carbon, locked in the plants and sediments. The combined figures suggest a potential capture and storage of a year's carbon emissions from 115 Million cars running on the roads in Southeast Asia's Member States. The region should change its energy, economic and environmental policies and focus more on renewables especially blue carbon ecosystems in mitigating climate change. The main hope for conserving the blue carbon ecosystems lies in a combination of science and sociocultural economics. The first step is accepting the importance of coastal carbon pools as a significant tool in mitigating climate change.

**S18-P5**

**Coastal wetland blue carbon synthesis: Recent outcomes and future opportunities**

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Tidal marshes, mangroves, and seagrass meadows collectively form some of the Earth's most productive ecosystems. They have the capacity to bury carbon, forming new soil mass as plants and soils respond dynamically to sea-level rise. However, our understanding of coastal wetlands as a carbon sink is far from certain. Wetlands can also be a source of emissions when carbon stocks are eroded, extracted due to development, or drained for agriculture. Tidal wetlands can also emit methane, a more potent greenhouse gas than carbon dioxide over the course of its atmospheric lifetime. The Coastal Carbon Research Coordination Network (RCN) is poised to take on the many challenges in the developing field of 'Blue Carbon' science and practice. Planned outreach activities include teaching researchers field methods, data management, and analytics via YouTube videos, webinars, and consultations. We will improve access to data by hosting open online literature reviews, web-based modeling tools, and a database of over 1,500 soil carbon profiles. In the coming years, we will also host a series of targeted meetings with the goal of generating high-level synthetic research products. Importantly, the structure and goals of the Coastal Carbon RCN will be flexible, responding to community input. Progress to date has provided lessons in the value and difficulties we must overcome to achieve impactful coastal carbon synthesis. It also provides us with context for research priorities going forward and quantifiable metrics by which we can judge how well we do over the next 5 years.

## **W3: Exploring potential ocean-based solutions to climate change impacts on marine biodiversity and ecosystem services**

### **W3-P1**

#### **Ocean governance in the Gulf of Guinea: Valuing planning as an ambitious path toward sustainable climate change solutions**

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As in many developing countries in the world, the impacts of climate change scenarios on the oceans, especially in context of sea level rise and ecosystem service provisions, have proven in recent years to constitute significant threats to the sixteen coastal countries of the Gulf of Guinea (GoG) region of Africa, stretching from Guinea Bissau downward to Angola. To face this situation, national, regional and international initiatives have been developed in aspects framed around mitigation and adaptation measures, however with absence of knowledge or eventually limited concern about the potential and centrality of a regional or transboundary spatial planning system for the GoG marine and coastal environments. This paper lies on reports and data from international, regional and national sources to unearth and stress on the need for a definition, development and integration of a transboundary marine spatial planning (MSP) framework in the region. The document considers three axis of analysis to address the value of the missing MSP element in the overall ocean governance scheme of the GoG, including the administrative, socioeconomic and environmental dimensions of the problem. Further, it concludes by urging GoG regional governments, organizations, and maritime actors to consider MSP in their agenda as an integral part of sustainable ocean-based solutions to climate effects, and also to setup a collaborative platform, under the watch of the African Union (AU), if the perspective is to curb the socioeconomic and environmental vulnerabilities of the countries in face of climate dynamics.

## **W6: Utilizing bioenergetics measurements and modeling to evaluate climate change effects on marine species and ecosystems**

### **W6-P1**

#### **Fish Bioenergetics 4.0: An R-Based Modeling Application**

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Fish Bioenergetics 4.0 (FB4) provides a user-friendly, menu-driven environment for bioenergetics modeling. FB4 uses an R-based analytical approach that is linked to a graphical user interface, making simulations easy even for users with little or no experience in R programming. The R programming approach enables timely updates and bug fixes, and can rely on feedback from users to continuously improve the application. Users can add new or modified parameter sets for additional species and incorporate modifications such as habitat-dependent functions (e.g., acidity, dissolved oxygen, salinity) that are not part of the default package. Because the core model code is accessible to users it can be incorporated as a module in larger ecological models if desired. During development of FB4, we conserved many aspects of the previous version of Fish Bioenergetics 3.0 while adding features that improved efficiency and ease of working from the user-interface. Fish Bioenergetics 4.0 contains 105 bioenergetics models representing 72 aquatic species. It is our hope that advances in the new modeling platform will attract a broad range of users while facilitating continued use of bioenergetics modeling to address ecological and management questions.

## **W7: What do seabirds reveal about the effects of climate change on the World's Oceans?**

### **W7-P1**

#### **What seabird communities can tell us about the effect of climate change - A case study**

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Although birds are highly mobile, many are restricted to specific habitats and can be important indicators of the condition of those habitats. As climate change modifies the distribution of specialized habitats, it influences the distribution of entire communities of birds. Some communities might find new opportunities as habitats on which they rely become more abundant, other communities might become increasingly rare as the habitats on which they rely become limited in extent. These climate-mediated changes in the abundance and distribution of birds in specialized habitats could be of grave concern for the conservation of rare species. Three search engines were used to collect review of literature on the research on the climate change and birds. The Web of Science from Science Citation Index was searched from 1980 to the present, Biological Abstracts from 1980 to 2017 and Google Scholar in 'Biology, Life Sciences and Environmental Sciences' subject area, with keywords 'birds' and 'climate change' up to 18 May 2017. The main objectives of the study was to a) illustrate patterns in geographical and latitudinal shifts of selected sea bird communities in temperate and tropical habitats, b) model the influence of climate change on conservation of select species, and c) translate individual species trajectories into a comparative assessment of ecological condition. The study specifically permitted to test the following hypotheses: a) increase in global temperatures tends to shift species distributions toward relatively colder microclimates, and b) owing to higher species diversity in the tropics, the indirect impacts of climate change through biotic factors (food plants, natural enemies, competitors, guild companions) were more pronounced than in relatively simpler temperate communities. The comparison of temperate and tropical habitats is an important strength of this study.

## **W8: Connecting climate, ocean and ecosystem observation – Ocean observation futures**

### **W8-P1**

#### **OBSERVA.PT - Observations on board national commercial ships to support the conservation of marine biodiversity in the Portuguese Seas**

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The main objective of the project OBSERVA.PT funded by the European Union and the Portuguese Government under the Mar2020 Programme is to implement appropriate marine environment monitoring technologies (satellites and continuous automatic recording equipment) for the production of operational oceanographic and meteorological information. More specifically the project will ensure long-term monitoring activities in the open ocean (e.g. oceanic MPA s), build bioceanographical time series and map their spatio-temporal variability to support the adaptive management of marine ecosystems, assess their biodiversity improve climate characterization in this region and improve meteorological forecasts for maritime activities. These observations will contribute to the baseline information for Marine Strategy Framework Directive (MSFD) descriptors of biodiversity (D1), non-indigenous species (D2), marine food web (D4; plankton, dolphins and whales) and the eutrophication (D5) classification of the Portuguese Seas, and to extend the Portuguese contribution to international organizations and programmes (e.g. EuroGOOS, Euro-Argo and JCOMM). We will install several meteorological stations and oceanographic equipment (e.g. thermosalinographs and fluorometers) on board cargo ships en route from Portugal Mainland to Madeira, Azores and Cape Vert Islands (Northeast Atlantic Ocean). The deployment of Argo floats in locations where there are observation gaps are also envisage, as well as the collections of water samples for phytoplankton and nutrient analysis. During the summer months two observers will board for whale and dolphins observations.

### **W8-P2**

#### **The Great Lakes: A visual description of the changes in weather patterns from 1979 to 2002, and water quality from 2002 to 2015**

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The Great Lakes contain 84% of North America's fresh water and provide critical resources to the local economy and environment. In recent decades, water clarity across most of the Great Lakes has increased, a trend observed both through field observation. While many of the changes in the Great Lakes can be traced to anthropogenic influences such as the introduction of invasive species, and industrial and agricultural pollution, the role of climate change and variability in modulating water clarity changes in the Great Lakes is poorly understood. Through an easy to follow visual, our poster will describe changes in the Great Lakes' weather pattern from 1979 to 2015, as well as their water quality from 2002 to 2015. The weather information was extracted from the North American Regional Reanalysis, while water quality data was estimated from MODIS (Moderate Resolution Imaging Spectroradiometer), an ocean color sensor.

## W8-P3

### Widespread microplastic distribution at a microtidal Amazon sandy beach

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Microplastics are widespread on the world's oceans and coastal systems, causing several impacts such as the release of toxic organic compounds and ingestion by the biota. Up to now, data on microplastic for the amazon coast is scarce and unpublished. Thus, we estimated microplastic abundance and distribution of the relatively preserved Corvina's beach at the northeastern, Brazilian amazon coast. The beach as limited recreational use, but its mangroves provide fisheries for local, traditional populations. During April, 2014, four areas of 400 m<sup>2</sup> were distributed along the nearly two km beach, where five trenches were randomly placed. The sand from each square meter trench was dug, collected and analyzed at three depth strata (0-20, 20-40 and 40-60 cm). Microplastic (250 to 5,000 µm) from each depth interval were separated by flotation in seawater and retrieved from the supernatant using a 250 µm sieve. The particles were counted and classified by aspect. We found 492.5±556.4 plastic particles.m<sup>-3</sup>, fibers represented up to 90% (possibly from fishery activities), while pellets were rare (<0,001%). The surface stratum showed the highest abundance, which decreased with depth (61.5%, 25% and 13.5% from surface to 40-60cm stratum). Despite the low to moderate abundance, microplastics were widespread on the whole beach and at the different depths. Even pristine beaches may now be contaminated by microplastics. The amazon coast should be considered by local and global initiatives to reduce plastics impacts in such important area for fisheries and traditional communities.



## **W9: Vulnerability of Low Elevated Coastal Zones (LE CZ) to SLR in changing oceans**

### **W9-P1**

#### **Impacts of sea-level rise on the Amazon Macrotidal Mangrove Coast**

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Brazil has the largest continuous mangrove area in the world, the Amazon Macrotidal Mangrove Coast (AMMC). Therefore, identifying the response of Brazilian mangroves to future sea-level changes is critical to understanding the potential impacts of climate change to this endangered but vital ecosystem. Since this extensive mangrove region is extremely difficult to study using traditional field-based methods, remote sensing and modeling techniques were used to simulate the response of eastern Amazonian mangroves to Sea-level rise (SLR), and to produce a vulnerability assessment for this section of the Brazilian coast. We used a spatially explicit model, based on cellular automata and Geographic Information System, to identify the intensity of migration and/or inundation of these mangroves for different IPCC scenarios of eustatic SLR. The simulation considers 90 elevation events from 0.01 to 0.97 m according an arithmetic progression of reason 0.01 m for the time interval from 2010 to 2100. At the end of the simulation (year 2100), the original mangrove area (4,180 km<sup>2</sup>) was reduced to 2,916 km<sup>2</sup>, representing a loss of 30.24%. Our simulation also showed significant landward migration of the mangroves, and the modeled loss of the original mangrove area was compensated by a net addition of 301 km<sup>2</sup> of new mangroves inland, a net increase of 7.2% in the total mangrove area (4,481 km<sup>2</sup> in 2100). The results of this research can help the identification of migration corridors for the Amazonian mangroves and the development of adaptation strategies in face of impending SLR.

### **W9-P2**

#### **Sea Level Rise along the Bangladesh Coast**

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The Bangladesh coast is a highly populated and is gaining international attention due to the acceleration of the global mean sea level rise. We compare 9 different sea level reconstructions over the period from 1960 to 2008 in order to estimate the sea level rise in the Bay of Bengal and in the Ganges–Brahmaputra delta. We find that the reconstructions best representing the sea level height is the SODA reconstruction based on the SODA Ocean General Circulation Model. The reconstructed time series have been validated by tide gauge and altimetric series. Between 1950 and 2012 the mean sea level rise in the Bay amounts to  $2.21 \pm 0.15$  mm/yr, a value larger than the global mean sea level rise over the same period. Over the altimetric period (1993-2012), the mean sea level rise of the Bay amounts to 2.75-3.83 mm/yr and the mean sea level of the delta rise to 3-5 mm/yr. We estimate that over the altimetric period, about 1-2 % of land has been lost and 1-1.5 million people have been forced to migrate. According to our estimates, by 2050 about 3-4% of land could be lost and 3 million people would be landless.

## **W10: Intercomparison of fisheries and marine ecosystem models**

### **W10-P1**

#### **Role of cephalopods in ecosystem functioning and evolution**

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Ecosystem structure and functioning are influenced by many biotic and abiotic factors. However, their evolution is often driven by key components or species. Because of their interaction with numerous elements of the food web and their high productivity, cephalopods have a key role in the transfer of nutrients through trophic levels. In a context of climate change and increasing fishing pressure, understanding cephalopods role is important as their fast cycle allows them to answer quickly to external pressure. Their abundance has already been seen to increase worldwide, while a combinations of factors caused an increase of interest from fisheries. If the development of ecosystem models is a great step towards a global understanding of marine systems functioning, they still suffer from limitations. We reviewed many models representing cephalopods and observed a need for improvement as models are poorly equipped, and often not used to their best capacities when it comes to cephalopods representation. We thus developed a model with a strong focus on cephalopods, using all the tools available and adding new processes to the model. We worked in the South East Australian region as a particularly high number of studies on cephalopods ecology have been conducted there. This allowed us to represent the key traits of cephalopods with details. To assess potential impact of cephalopods on system evolutions we distinctly represented species of interest for fisheries or species observed to undergo ecological changes due to climate change. We then simulated various scenarios combining different fisheries management strategies and climate scenarios, to assess systems evolution and potential management opportunities and mitigation of human exploitation.

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