INTERNATIONAL SYMPOSIUM

DRIVERS OF DYNAMICS OF SMALL PELAGIC FISH RESOURCES

BOOK OF ABSTRACTS

MARCH 6–11, 2017 VICTORIA, CANADA

www.pices.int/smallpelagics2017

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For convenience all presentations (oral and posters) include the presenter's name only.
Please refer to the Book of Abstracts for the full list of co-authors.

Symposium Organizers

Symposium Convenors

Jürgen Alheit (ICES)
Germany

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Merete Tandstad (FAO)
FAO Fisheries and Aquaculture Department

Session Convenors

Session 1: *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context*

Emanuele Di Lorenzo (Georgia Institute of Technology, USA)

Dimitri Gutierrez (IMARPE, Peru)

Svein Sundby (Institute of Marine Research, Norway)

Yongjun Tian (Ocean University of China, China)

Session 2: *External drivers of change in early life history, growth and recruitment processes of small pelagic fish*

David Checkley (Scripps Institution of Oceanography, UCSD, USA)

Susana Garrido (Instituto Português do Mar e da Atmosfera, Portugal)

Pierre Petitgas (IFREMER, France)

Akinori Takasuka (National Research Institute of Fisheries Science, FRA, Japan)

Session 3: *The role of small pelagic fish in food web dynamics between plankton and top predators*

Arnaud Bertrand (Institut de Recherche pour le Développement, France)

Salvador Lluch-Cota (CIBNOR-CONACYT, Mexico)

William Peterson (Northwest Fisheries Science Center, NMFS, USA)

Session 4: *Comparison of methods for assessment of small pelagic fish populations*

Miguel Bernal (FAO, General Fisheries Commission for the Mediterranean)

Jennifer Boldt (Department of Fisheries and Oceans, Canada)

Momoko Ichinokawa (National Research Institute of Fisheries Science, FRA, Japan)

Reidar Toresen (Institute of Marine Research, Norway)

Session 5: *Future challenges for ecosystem-based management of highly variable fish populations*

Warrick (Rick) Fletcher (Department of Fisheries, WA, Australia)

David Reid (Irish Marine Institute, Ireland)

Merete Tandstad (FAO Fisheries and Aquaculture Department)

Andres Uriarte (AZTI, Spain)

Session 6: *Small pelagic fish and humans – Social, economic and institutional dimensions*

Manuel Barange (FAO, Fisheries and Aquaculture Policy and Resources Division)

Marloes Kraan (IMARES, The Netherlands)

Mitsutaku Makino (Fisheries Research Agency, Japan)

Jörn Schmidt (University of Kiel, Germany)

Rashid Sumaila (Fisheries Centre, University of British Columbia, Canada)

Workshop Convenors

Workshop 1: *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context*

Jürgen Alheit (Germany)

Emanuele Di Lorenzo (Georgia Institute of Technology, USA)

Ryan Rykaczewski (University of South Carolina, USA)

Svein Sundby (Institute of Marine Research, Norway)

Workshop 2: *Methods and techniques for sampling and assessing small pelagic fish populations*

Jennifer Boldt (Department of Fisheries and Oceans, Canada)

Matthew Baker (North Pacific Research Board, USA)

Miguel Bernal (FAO, General Fisheries Commission for the Mediterranean)

Stylianos (Stelios) Somarakis (Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Greece)

Workshop 4: *Modeling migratory fish behavior and distribution*

Shin-ichi Ito (AORI, University of Tokyo, Japan)

Enrique Curchitser (Rutgers University, USA)

Workshop 5: *Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies*

Myron Peck (University of Hamburg, Germany)

Kirstin Holsman (AFSC, NOAA-Fisheries, USA)

Shin-ichi Ito (AORI, University of Tokyo, Japan)

Laure Pecquerie (IRD, France)

Workshop 6: *Remote sensing and ecology of small pelagics*

Shubha Sathyendranath (Plymouth Marine Laboratory, UK)

Grinson George (Central Marine Fisheries Research Institute, India)

Nandini Menon (Nansen Environmental Research Centre India, India)

Trevor Platt (Plymouth Marine Laboratory, UK)

Workshop 7: *Simulation approaches of forage fish populations for management strategy evaluations*

Margaret Siple (University of Washington, USA)

Laura Koehn (University of Washington, USA)

Notes for Guidance

Location

The entire symposium (all sessions and workshops) will be held on the first floor at the Victoria Conference Centre (VCC) located at 720 Douglas Street, Victoria (http://victoriaconference.com/).

Registration

The registration desk will be set in the Pre-function Area 1A.
The desk will be open from 15:00–17:00 on March 5, from 8:00–18:00 on March 6–10, and from 8:30–14:30 on March 11.

Presentations

In order to allow the sessions to run smoothly, and in fairness to other speakers, please note that all presentations are expected to adhere strictly to the time allocated. All authors should designate at least 5 minutes for questions. Authors can download their presentations directly to the computers where the session/workshops will be held.

Important: Please rename your files - time-name.ppt (*e.g.* 0900-Smith.ppt, 1530-Kim.ppt).

If complications occur due to incompatibilities between PCs and Macs, Macintosh owners may use their own computers to make presentations.

Posters

Posters will be on display in Saanich Room/Pre-function Area 1A from the morning of March 6 until noon of March 10. Poster presenters are expected to be available at their posters for at least one hour to answer questions during the two Poster Sessions/Receptions to be held from 18:00–20:30 on March 7 and March 9. To facilitate planning of poster viewing, authors should leave a note with their posters to notify viewers on the times when they will be available.

Internet access

A few computers with Internet access will be available for participants. Participants can also purchase the self-serve Wi-Fi connection ($5/device/day rate).

Social activities

Welcome Reception

March 6 (18:30-21:00)
Royal British Columbia Museum

The Welcome Reception for all participants and registered guests will be held at the Royal British Columbia Museum (http://royalbcmuseum.bc.ca/).
The Museum is located at 675 Belleville St, Victoria, BC, V8W 9W2, a short walk from the meeting venue.

Wine & Cheese Poster Session Reception

March 7 & March 9 (18:00-20:30)
Victoria Conference Centre (Saanich Room and Pre-function Area 1A)

Two "Wine & Cheese" Poster Sessions held at the Victoria Conference Centre will allow participants and registered guests to roam around the poster displays and chat with presenters while sipping beer or wine, and nibbling on hot and cold hor d'oevres.

Welcome

We welcome you to the international symposium on "*Drivers of dynamics of small pelagic fish resources*". Small pelagic fish provide about 25% of the total annual yield of capture fisheries, and the well-being of many coastal communities around the world, particularly in developing countries, is critically dependent on these resources. Small pelagic population sizes undergo extreme fluctuations in abundance and geographic distribution due to the impact of environmental and anthropogenic influences. In spite of many internationally coordinated research efforts, we still do not have sufficient knowledge about the drivers of small pelagic fish recruitment and, particularly, the interactive effects of environmental and anthropogenic factors.

In 1983, the Fisheries and Agriculture Organization (FAO) and Intergovernmental Oceanographic Commission (IOC) organized an international symposium titled "*The Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources*" in San José, Costa Rica (FAO Fisheries Report 291, 1983, 3 Volumes). The symposium was a major success and inspired many research efforts on small pelagics for the next three decades. It was the first time many of those attending the symposium were confronted with the phenomenon of small pelagic fish population abundances varying synchronously in many unconnected regions of the global ocean. This is an issue that we are still attempting to understand, as the distances between the small pelagic stocks are large, atmospheric and ocean connections are weak and unclear, and mechanisms are unresolved.

There has been no global symposium on small pelagic fish since 1983, and the exchange of information about them has declined on a global basis since the end of the Small Pelagics and Climate Change (SPACC) project of GLOBEC in 2008. The goal of this symposium is to revitalize global international cooperation on investigations of small pelagic fish, and to identify, discuss and develop a framework to address unresolved questions such as the impact of climate and/or fishing pressure on the resilience of small pelagic populations using a comparative approach.

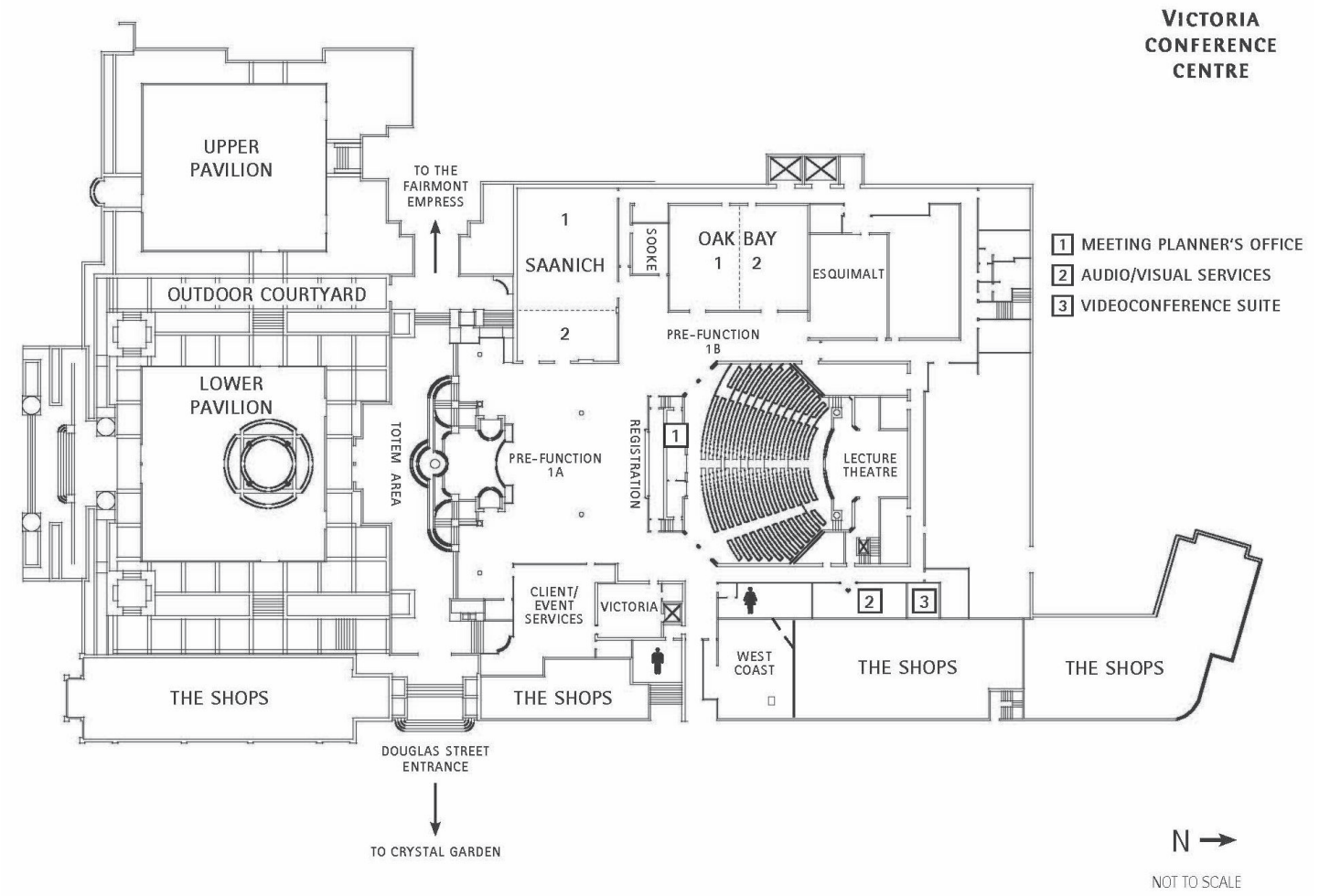
With deep satisfaction we acknowledge that more than 250 scientists from almost 40 countries are attending the symposium and that about 270 abstracts have been submitted, demonstrating the wide interest in small pelagic fish issues. We are particularly happy about the participation of experts from the fields of climate research, physical oceanography, zooplankton and socio-economic sciences, showing the interdisciplinary nature of research on small pelagics.

We thank the Secretariats of the organizing institutions, PICES and ICES, for their hard work in preparing this event, and express our gratitude to all the numerous sponsors – without their generous support this symposium would not have been possible. Our thanks go also to the Scientific Steering Committee and the session and workshop conveners and invited speakers for their commitment.

We expect this symposium to be as successful as the 1983 event. To reach this goal, we look forward to your intense cooperation this week.

Jürgen Alheit, Yoshioki Oozeki, Alexander Bychkov and Wojciech Wawrzynski
Symposium Convenors and Coordinators

Level I floor plan



List of Sessions and Workshops

S1	Mar. 6-8, 10	Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context
S2	Mar. 6-8	External drivers of change in early life history, growth and recruitment processes of small pelagic fish
S3	Mar. 9-10	The role of small pelagic fish in food web dynamics between plankton and top predators
S4	Mar. 8	Comparison of methods for assessment of small pelagic fish populations
S5	Mar. 9	Future challenges for ecosystem-based management of highly variable fish populations
S6	Mar. 7	Small pelagic fish and humans – social, economic and institutional dimensions
W1	Mar. 11	Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context
W2	Mar. 11	Methods and techniques for sampling and assessing small pelagic fish populations
W4	Mar. 11	Modeling migratory fish behavior and distribution
W5	Mar. 11	Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies
W6	Mar. 11	Remote sensing and ecology of small pelagics
W7	Mar. 11	Simulation approaches of forage fish populations for management strategy evaluations

Program at a Glance

Monday, March 6				
09:00 12:30	**Opening Ceremony, Plenary Session** [Lecture Theatre]			
14:00 18:00	**Session 1 (Day 1)** [Lecture Theatre]		**Session 2 (Day 1)** [Saanich Room]	
18:30 21:00	**Welcome Reception** [Royal BC Museum]			
Tuesday, March 7				
09:00 10:10	**Plenary Session** [Lecture Theatre]			
10:30 18:00	**Session 1 (Day 2)** [Lecture Theatre]	**Session 2 (Day 2)** [Saanich Room]	**Session 6** [Esquimalt Room]	
18:00 20:30	**Poster Session / Reception** [Oak Bay Room / Pre-function Area]			
Wednesday, March 8				
09:00 10:10	**Plenary Session** [Lecture Theatre]			
10:30 18:00	**Session 1 (Day 3)** [Lecture Theatre]	**Session 2 (Day 3)** [Saanich Room]	**Session 4** [Esquimalt Room]	
Thursday, March 9				
09:00 10:10	**Plenary Session** [Lecture Theatre]			
10:30 18:00	**Session 3 (Day 1)** [Lecture Theatre]		**Session 5** [Saanich Room]	
18:00 20:30	**Poster Session / Reception** [Oak Bay Room / Pre-function Area]			
Friday, March 10				
09:00 12:30	**Session 1 (Day 4)** [Lecture Theatre]		**Session 3 (Day 2)** [Saanich Room]	
14:00 17:30	**Plenary Session, Closing Ceremony** [Lecture Theatre]			
Saturday, March 11				
09:00 12:30	**Workshop W1** [Saanich 1 Room]	**Workshop W2** [Oak Bay 1]	**Workshop W4** [Esquimalt Room]	**Workshop W6** [Oak Bay 2]
14:00 18:00		**Workshop W7** [Oak Bay 1]	**Workshop W5** [Esquimalt Room]	

Coffee/Tea Breaks will take place every day in the morning and afternoon.
Lunch breaks are scheduled approximately from 12:30-14:00.

Schedule at a Glance, March 6

Plenary

9:00 **Opening Ceremony**

9:30 **Andrew Bakun (General Plenary)**
Progress in small pelagic fish research in the 3½ decades since 'Costa Rica'

10:15 ***Coffee/Tea Break***

10:40 **Shoshiro Minobe (General Plenary)**
Causality linkages in atmosphere, ocean and marine ecosystem over the North Pacific: Modes, processes and prediction

11:15 **David Field (Plenary S1)**
Fish scale records from California and Peru reveal new paradigms of variability in climate and small pelagic fish

11:50 **Stylianos Somarakis (Plenary S2)**
From egg production to year class strength: A full life cycle perspective of small pelagic fish recruitment

12:25 ***Lunch***

S1, Day 1 (Lecture Theatre) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context*		**S2, Day 1 (Oak Bay Room)** *External drivers of change in early life history, growth and recruitment processes of small pelagic fish*
14:00	**Introduction by Convenors**	**Introduction by Convenors**
14:10	**Bryan A. Black (Invited)** Synchrony in climate and biological response within and among the Benguela and California Current ecosystems	**Dominique Robert (Invited)** Revealing the link between prey availability during the larval stage and recruitment strength in small pelagic fish
14:40	**Carmen Grados** Interdecadal upper ocean hydrology of the Northern Humboldt Current System and its impact on the small pelagic fish distribution	**Paul Gatti** Impact of seasonal environmental variability on the bioenergetics strategy of anchovy and sardine: A combined data and modelling study in the Bay of Biscay
15:00	**Karen Walker** Environmental impact on fluctuations of juvenile sardine (*Strangomera bentincki*) in the central-southern Chile (32°-47°S)	**Rebecca G. Asch** Testing the reliability of species distribution models: How stable are relationships between small pelagic fishes and oceanographic conditions in the southern California Current ecosystem?
15:20	**Antonio Fernando Aranis** Conceptual model for common sardine (*Strangomera bentincki*) in the south central zone of Chile (32°-47°S)	**Øystein Skagseth** Environmental drivers of peak recruitment years of Norwegian Spring Spawning Herring (*Clupea harengus* L.)
15:40	***Coffee/Tea Break***	***Coffee/Tea Break***

Schedule at a Glance, March 6

S1		S2, Day 1	
16:00	**Giancarlo Moron** Effects of ENSO phases on Peruvian anchovy spatial aggregation patterns	**Jens-Otto Krakstad** **(*by Øystein Skagseth*)** Oceanographic conditions and runoff from Congo River as drivers for *Sardinella* recruitment off south-western Africa
16:20	**Carola Hernández Santoro** Effects of El Niño 1997-98; 2002-03 and 2015-16 in spatial distribution, concentration of catch and reproductive activity of anchovy in northern Chile	**Guido Plaza** Fast growth and early age-at-recruitment of the anchovy (*Engraulis ringens*): Evidence from interannual monitoring of otolith microstructure in northern Chile
16:40	**Carolina Lang** Modelling the habitat of anchovy (*Engraulis ringens*) between 2007 - 2016 off the coast of the Southeast Pacific	**Emma Pascoe** Quantifying interannual variability in growth and condition of juvenile Pacific herring (*Clupea pallasii*) in the Strait of Georgia, BC
17:00	**Josymar Torrejon-Magallanes** **(*by Luis Wenchang Lau-Medrano*)** Displacements of the Peruvian anchoveta stocks in relation to environmental conditions: An analysis using length structure analysis from Vessel Monitoring System information	**Erling Kåre Stenevik** Mackerel predation on herring larvae during summer feeding in the Norwegian Sea
17:20	**Dimitri Gutierrez** Multifarious anchovy and sardine regimes in the Humboldt Current System during the last 150 years	**Eneko Bachiller** Effects of Atlantic mackerel predation on early life stages mortality of anchovy and sardine
17:40	**Criscely Luján-Paredes** Ontogenic variability of the ecological niche of Peruvian anchoveta (*Engraulis ringens*): Impacts on its present and future distribution	**Poster Presentations**
18:00	**Session 1, Day 1 ends**	**Session 2, Day 1 ends**

Schedule at a Glance, March 7

Plenary

9:00 **Ratana Chuenpagdee (Plenary S6)**
Small fish, big stake: Vulnerability and adaptation of small-scale small pelagic fisheries to global changes

9:35 **Manuel Barange (Plenary S6)**
State of small pelagic fish resources and its implications for food security and nutrition

10:10 ***Coffee/Tea Break***

S1, Day 2 (Lecture Theatre) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context*		**S2, Day 2 (Oak Bay Room)** *External drivers of change in early life history, growth and recruitment processes of small pelagic fish*	**S6 (Esquimalt Room)** *Small pelagic fish and humans – Social, economic and institutional dimensions*
10:30	**Introduction by Convenors**	**Introduction by Convenors**	**Introduction by Convenors**
10:40	**David M. Checkley, Jr.** Climate, anchovy and sardine	**Reidar Toresen** Climate change as a causative factor in sustained reduced recruitment in Norwegian spring-spawning herring	**Rashid Sumaila** A simple bio-economic model of the effects of subsidies on small scale (pelagic) fisheries
11:00	**Dimitri Gutiérrez** Recent trends in the Peruvian Coastal Upwelling Ecosystem and implications for the anchovy habitat	**Grea Groenewald** Influence of temperature and food availability on anchovy (*Engraulis encrasicolus*) dynamics as seen through a Dynamic Energy Budget (DEB) model	**Poster Presentations**
11:20	**Jorge Csirke** Evidences anthropogenic and environmentally driven regime shifts in Peruvian pelagic fisheries	**William Duguid** Historical fluctuations and recent observations of Northern Anchovy in the Salish Sea	**Marloes Kraan** Understanding the fishery and value chain of anchovy (Keta Schoolboys) in Ghana
11:40	**Renato Guevara-Carrasco (*by Blgo Miguel Ñiquen Carranza*)** Are there early signals of a new warmer "sardine cycle" in the Peruvian upwelling system? Some implications for fisheries management	**Claudia Soares** Validation of daily increments in the otoliths of Atlanto-Iberian sardine larvae (*Sardina pilchardus* Walbaum, 1792) reared at three different temperatures	**Katie Schleit** Management of small pelagics in Atlantic Canada: A case study of herring and mackerel
12:00	**Ana Alegre** Diet diversity of jack and chub mackerels and ecosystem changes in the northern Humboldt Current system: A long-term study	**Violaine Shikon** Larval capelin dynamics in coastal embayments of eastern Newfoundland	**Claus R. Sparrevohn** A spatial based management system for the sandeel fishery in the North Sea
12:20	**Daniel Grados** Impact of ocean stratification on small-scale physical oases for pelagic life	**Tessa B. Francis** Does the early bird catch the worm? Shifts in the spawn timing of Pacific herring (*Clupea pallasii*) in Puget Sound, USA, and consequences for local abundance trends	***Lunch***
12:40	***Lunch***	***Lunch***	
14:00	**Joana Boavida-Portugal** Global diversity and abundance of small pelagic fishes in the end of the 21st century	**Pierre Petitgas** On linking variability in early growth to habitat occupancy and mortality later in life: Anchovy in the Bay of Biscay	**Ruby P. Napata** Is closing the best option? The case of seasonal closure for sardine fishery in the Visayan Sea, Philippines
14:20	**Sam McClatchie** Collapse and recovery of forage fish populations before commercial fishing	**Aril Slotte** Use of otolith microstructure analyses to study the relation between larval hatching time, growth and survival in Norwegian spring spawning herring	**Momoko Ichinokawa** A variety of effort management and its quantitative evaluation in the Pacific purse seine fishery targeting small pelagic fish

Schedule at a Glance, March 7

	S1, Day 2	S2, Day 2	S6
14:40	**Ruben Rodriguez-Sanchez** Tracking the spatial dynamic of sardine abundance changes in the California Current large marine ecosystem: An approach to elucidate local and broad scale environmental drivers and their interactions	**Claudia Günther** Another critical period: Physiological limits determine recruitment success during the post-larval stage of a temperate clupeid (*Sprattus sprattus* L.)	**Mimi E. Lam** A values- and ecosystem-based management approach to the Pacific herring fishery conflict in Haida Gwaii, Canada
15:00	**Juan P. Zwolinski** Use of environmental indices to predict the recruitment of Pacific sardine	**Florian Eggers** Do epigenetic effects of parental salinity conditions in herring influence subsequent offspring reproductive success?	**Jeff Scott** Identifying stakeholder values in British Columbia's herring fisheries
15:20	**Dimitris V. Politikos** Climate variability and recruitment dynamics of sardine in the California Current: A mechanistic analysis of an end-to-end model	**Akira Hayashi** Combination of income- and capital-breeder type stocks of Japanese anchovy population	**Anne Shaffer** Linking large-scale dam removal and forage fish restoration and conservation: Observations from the Elwha Dam removals
15:40	***Coffee/Tea Break***	***Coffee/Tea Break***	***Coffee/Tea Break***
16:00	**Désirée Tommasi** **(*by David M. Checkley, Jr.*)** Seasonal climate predictions to improve forage fish management	**Thassya C. dos Santos Schmidt** How do Atlantic herring and Pacific herring compare in terms of reproductive investment and adult body growth?	**Mitsutaku Makino** A social-ecological approach for the full utilization of pelagic species alternation around Japan
16:20	**William J. Sydeman** Non-fishery collapse of northern anchovy in California: Climatic and biotic hypotheses	**Andres Ospina-Alvarez** Designing a reproductive resilience index for small pelagic fish in the southern Humboldt Current Upwelling Ecosystem	Panel Discussion
16:40	**Romeo Saldívar-Lucio** Primary productivity contribution to climate-catch models of Pacific sardine	**Jose-María Quintanilla** Comparative early life trophodynamics and larval growth of Alborán Sea sardine environmentally distinct larval habitats (Bays of Málaga and Almería) (*Sardina pilchardus*) (W Mediterranean)	
17:00	**Doug Hay** Temporal changes in size-at-age: Impact and implications on reproductive biology and egg density of Pacific herring in British Columbia	**Betsy Buitrón** Reproduction history of Peruvian anchovy and its relationship with environmental changes 1961 - 2015	
17:20	**Sourav Maity** Exceptional fish beaching off Arthungal, Alappuzha, along the southwest coast of India: Search for the possible cause	**Fabian Zimmermann** Drivers of recruitment dynamics in northeast Atlantic pelagic fish stocks	
17:40	**Momodou S. Jallow** **(*cancelled)*** Impact of climate change on the population of SPF resources of the Gambia	**Sandra Emry** **(*cancelled)*** Site specific and inter-annual variation (2013-2016) in growth rates and jellyfish predation of larval Pacific Herring (*Clupea pallasii*) on British Columbia's (Canada) Central Coast	
18:00	**Session 1, Day 2 ends**	**Session 2, Day 2 ends**	**Session 6 ends**

Schedule at a Glance, March 8

Plenary

9:00 **Ryan R. Rykaczewski (General Plenary)**
Climate impacts on upwelling and the planktonic prey of anchovy and sardine in eastern boundary currents

9:35 **Reidar Toresen (Plenary S4)**
Methods for assessment of small pelagic fish populations, - do we cope with it?

10:10 ***Coffee/Tea Break***

S1, Day 3 (Lecture Theatre) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context*		**S2, Day 3 (Oak Bay Room)** *External drivers of change in early life history, growth and recruitment processes of small pelagic fish*	**S4 (Esquimalt Room)** *Comparison of methods for assessment of small pelagic fish populations*
10:30	**Introduction by Convenors**	**Introduction by Convenors**	**Introduction by Convenors**
10:40	**Vanessa Izquierdo-Peña** Revisiting the regime problem hypothesis: 25 years later	**Myron Peck** Physiological modelling of the foraging and growth of early life stages of small pelagic fish: Fish don't eat temperature	**James Ianelli (Invited)** Successful management of small pelagics within a large international region: The case for collaborative assessment work within the recently formed South Pacific Regional Fisheries Management Organization
11:00	**Shuyang Ma** Variations in the catches of small pelagic fishes from China seas and their responses to climatic regime shifts	**Marion Claireaux** Is fishing driving energy acquisition and allocation changes in the Norwegian Spring-Spawning herring?	11:10 **Sherri C. Dressel and Jaclyn S. Cleary** Assessment of Pacific herring (*Clupea pallasii*) populations in the northeast Pacific Ocean
11:20	**Aida Sartimbul** Catch dynamics of small pelagic fishes in Bali Strait and South Java Sea in relation to the climatic regime shift: Case study on *Sardinella lemuru*	**Leonardo Castro** Variations in vertical distribution of anchoveta eggs under contrasting spawning habitat characteristics: An environmental or maternal effect?	11:30 **Douglas P. Swain** Incorporating time-varying fishery catchability in assessment models for Atlantic herring (*Clupea harengus*)
11:40	**Mutiara R. Putri** The influence of ocean dynamics and climate changes on the Lemuru (*Bali Sardinella*) abundance in the Bali Strait, Indonesia	**Hwahyun Lee** Observed pattern of diel vertical migration of Pacific mackerel larvae and its implication for spatial distribution off the Korean Peninsula	11:50 **Divya A. Varkey** Length-based assessment method for data-limited fisheries of small pelagic species
12:00	**Miguel Ñiquen** Size structure based associations between anchoveta and other pelagic resources in Peruvian waters	**Patricia M. Ayón** Distribution of anchovy and sardine eggs and larvae in the Humboldt Current System of Peru from 1960-2014: Implications for fish abundance and reproduction	12:10 **John T. Trochta** Insights into the recovery of Atlantic and Pacific herring following population collapse
12:20	***Lunch***	**Guðmundur J. Óskarsson** Development and nature of widespread and long-lasting *Ichthyophonus hoferi* outbreak in Icelandic summer-spawning herring	12:30 ***Lunch***
		12:40 ***Lunch***	
14:00	**Brian P.V. Hunt** Energy transfer efficiency from zooplankton to forage fish over a eutrophic to oligotrophic gradient in global pelagic food-webs	**Sebastián Vásquez** A space oddity: The case of the anchoveta (*Engraulis ringens*) in southern Humboldt Current system	**Geneviève Nesslage** Evaluating the performance of production models with time-varying parameters for assessing small pelagic fish in dynamic ecosystems

Schedule at a Glance, March 8

	S1, Day 3	S2, Day 3	S4
14:20	**Pablo Brosset** Small pelagic fish in the Mediterranean Sea: Alarming body condition and size decline during the last decades	**Guillermo Boyra** Spatial dynamics of juvenile anchovy in the Bay of Biscay	**Zacharie Sohou** **(*by Victor O. Okpeitcha*)** Pelagic fish resources stocks assessment in southern part of the Gulf of Guinea: Benin Continental Shelf
14:40	**George Triantafyllou** A full-life-cycle multispecies IBM for Mediterranean small pelagic fish	**Timothée Brochier** Climate change scenario experiments predict a future reduction in small pelagic fish recruitment in the Humboldt Current System	**Stephani Zador** A new view on forage fish trends in relation to environmental conditions in the Gulf of Alaska
15:00	**Claire Saraux** Population changes in small pelagic fish of the Gulf of Lions: A bottom-up control?	**W. Scott Pegau** Herring research and monitoring in Prince William Sound, Alaska	**Matthew Baker** Pacific sand lance – Assessment of benthic habitat, population structure, abundance, distribution and response to environmental drivers in the San Juan Archipelago
15:20	**Nikolaos Nikolioudakis** Spatio-temporal modelling of Northeast Atlantic mackerel (*Scomber scombrus*) distribution: Introducing estimates of uncertainty and going beyond 'visual' correlations	**Daigo Kamada** Diet characterization and link between feeding success and recent growth of capelin (*Mallotus villosus*) during early ontogeny	**Emily M. Liljestrand** Estimating migration and mortality of adult Atlantic menhaden with data from a large-scale mark-recapture study
15:40	***Coffee/Tea Break***	***Coffee/Tea Break***	***Coffee/Tea Break***
16:00	**Jürgen Alheit** Ocean-atmosphere interactions related to the AMO caused simultaneous 'regime shift'-like changes in ecosystems of eastern North Atlantic and Mediterranean in the mid-1990s	**Franziska Bils** Exploring the microzooplankton-ichthyoplankton link: A combined field and modeling study of Atlantic herring (*Clupea harengus*) in the Irish Sea	**Martin A. Pastoors** New insights into small pelagics from industry self-sampling in Europe, West-Africa and the South Pacific
16:20	**Maite Erauskin** Will climate change impact the anchovy spawning habitat in the Bay of Biscay?	**Quentin Queiros** Mechanisms underlying bottom-up controls of small pelagics in the Gulf of Lions through experimental studies	**Andrés Uriarte** ***(cancelled)*** Monitoring by direct surveys and integrated assessment of the Bay of Biscay anchovy (1989-2016) for the provision of management advice
16:40	**Piera Carpi** Storytelling based on a data limited situation: Dynamics of a small pelagic community in the Northeast Atlantic	**Sachihiko Itoh** Modeling large-amplitude recruitment variability of small pelagic fish	**David A. Demer** Use of a potential habitat model to sample Pacific sardine abundance
17:00	**Anna H. Olafsdottir** Expansion of Northeast Atlantic mackerel (*Scomber scombrus*) in the Nordic seas from 2007 to 2015 in relation to stock size and environmental conditions	**Matthias Paulsen** Stepping forward in understanding recruitment variability of western Baltic herring	**Wade D. Smith** Discerning connectivity and natal fidelity of Pacific herring (*Clupea pallasi*): Inferences on population structure from otolith chemistry
17:20	**Geir Huse** Norwegian spring spawning herring migration and feeding at the Arctic front	**Jennifer Boldt** Juvenile Pacific Herring (*Clupea pallasi*) trophic linkages in the Strait of Georgia, British Columbia	**Concluding remarks by Convenors**
17:40	**Svein Sundby** Multidecadal climate signal and its association with the Nordic Seas pelagic fish complex and their zooplankton prey	**Concluding remarks by Convenors**	**Session 4 ends**
18:00	**Session 1, Day 3 ends**	**Session 2 ends**	

Schedule at a Glance, March 9

Plenary

9:00 **Sophie Bertrand (Plenary S3)**
How much, where and when? A seabird eye-view on forage fish dynamics and management

9:35 **Kwame A. Koranteng (Plenary S5)**
Will ecosystem approach to fisheries improve our understanding of, and ability to manage, human impacts on variable fish populations?

10:10 ***Coffee/Tea Break***

S3, Day 1 (Lecture Theatre) *The role of small pelagic fish in food web dynamics between plankton and top predators*		**S5 (Oak Bay Room)** *Future challenges for ecosystem-based management of highly variable fish populations*
10:30	**Introduction by Convenors**	**Introduction by Convenors**
10:40	**Susana Garrido (Invited)** To eat, to be eaten, and a lot of questions: Understanding the trophic ecology of small pelagic fish	**Verena Trenkel (Invited)** What are the challenges for ecosystem-based management of highly variable fish populations?
11:10	**Marta Albo-Puigserver** Ecological and functional role of key fish species from the pelagic community of the Mediterranean Sea	**Timothy Essington** Economic benefits from ecosystem-based forage fish management depends on fishing history
11:30	**Arezoo Vahabnezhad** Food web structure and small pelagic fish interactions in the Caspian Sea ecosystem, Iranian waters	**Szymon Surma** A reassessment of carrying capacity estimates for Northeast Pacific herring stocks
11:50	**Piotr Margonski** Feeding conditions for small pelagic fish in the southern Baltic Sea based on the long-term analyses of the zooplankton abundance and community structure changes in response to various environmental stressors	**Gustavo F. Carvalho-Souza** **(*by Francisco Baldó*)** Natural and anthropogenic factors in the Guadalquivir estuary affect the abundance of anchovy in the Gulf of Cadiz (SW Spain)
12:10	**Paul Kotterba** Atlantic herring *Clupea harengus* within the coastal food web of shallow inshore waters	**Rosamma Stephen** Factors for the fluctuations in the catches of oil sardine and Indian mackerel along southwest coast of India: Perspectives of fishery scientists and fishermen
12:30	***Lunch***	***Lunch***
14:00	**Cecilia E.K. Kvaavik** Trophic interactions of Atlantic mackerel (*Scombrus Scomber*) and herring (*Clupea harengus*) on the Icelandic shelf – A study of diet using stable nitrogen and carbon isotopes	**Isaac C. Kaplan** A multi-model approach to understanding the role of Pacific sardine in the California Current food web
14:20	**Tore Johannessen** Overfishing of planktivorous fishes may result in smaller plankton and less efficient energy flow to higher trophic levels	**Margaret C. Siple** Evaluating harvest strategies for small pelagic fish

Schedule at a Glance, March 9

	S3, Day 1	S5
14:40	**Daigo Kamada** Pre-wintering adult capelin (*Mallotus villosus*) feeding dynamics off the northeast coast of Newfoundland and Labrador	**Laura E. Koehn** Evaluating alternative forage fish harvest control rules from a seabird perspective
15:00	**Andrew Bakun** A potential role of small pelagic fishes in combating dynamic deoxygenation occurring within intensified upwelling circulations	**Mariano Gutierrez** A claim for precautionary adaptive management in upwelling systems. The case of Peruvian anchovy (*Engraulis ringens*) fishery
15:20	**Arnaud Bertrand** The paradox of fish abundance in the Northern Humboldt Current system: Why is it so productive?	**Filomena Vaz-Velho** The importance of fisheries independent surveys for an ecosystem approach to management of small pelagic fisheries
15:40	***Coffee/Tea Break***	***Coffee/Tea Break***
16:00	**Sergio Neira** Ecosystem role of *Sprattus fuegensis* and impacts of its exploitation on the sustainability of other fishery resources	**Nis Sand Jacobsen** The contribution of natural mortality to the decline and recovery in forage fish
16:20	**Yuji Okazaki** Long-term changes in prey items of larvae and juveniles of two clupeoid species in the Kuroshio-Oyashio transition region	**Andrés Uriarte** Managing the Bay of Biscay anchovy: Fishery requirements vs sustainability given recruitment uncertainty
16:40	**James J. Ruzicka** Do jellyfish blooms affect small pelagic fishes in coastal marine environments?: A comparative analysis of three coastal ecosystems	**Szymon Smoliński** Incorporation of environmental drivers in the prediction of pelagic stocks recruitment in the Baltic Sea using random forest algorithms
17:00	**Mary Hunsicker** **(*by Richard Brodeur*)** Effects of warming ocean conditions on feeding ecology of small pelagic fishes in coastal ecosystems	**Ruben Alarcón** Ecosystem impacts of applying single-species versus multiple-species MSY in the Patagonian sprat fishery (*Sprattus fuegensis*) in the inner sea ecosystem of southern Chile
17:20	**Kym C. Jacobson** Using trophically transmitted parasites to help understand the role and dynamics of small pelagic fish in the California Current	**Sonia Sánchez** Management strategy evaluation for the Bay of Biscay anchovy long term management plan definition
17:40	**Evgeny Pakhomov** Feeding dynamics of Pacific herring (*Clupea pallasi*) in the northeastern Pacific coast of Canada	**Aziza Lakhnigue** More than fifteen years of collaboration on the assessment of small pelagic fish off Northwest Africa: Lessons learned and future perspectives
18:00	**Session 3, Day 1 ends**	**Session 5 ends**

Schedule at a Glance, March 10

	S1, Day 4 (Lecture Theatre) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context*	**S3, Day 2 (Oak Bay Room)** *The role of small pelagic fish in food web dynamics between plankton and top predators*
9:00	**Emanuele Di Lorenzo** Tendency for climate synchrony and amplification in global fish populations	**Szymon Surma** Whale population recovery and forage fish in a Northeast Pacific ecosystem
9:20	**Tatsuya Sakamoto** Reproducing migration history of Japanese sardine using otolith $\delta^{18}O$ and a data assimilation model	**Tamsyn Tyler** The feeding ecology of mesopelagic fishes (*Lampanyctodes hectoris* and *Maurolicus walvisensis*) off the South African west coast: A comparative analysis using stable isotope and dietary data
9:40	**Hiroaki Saito** A story starting from the wind: A synthesis of the collapse of Japanese sardine stock	**William J. Sydeman** Small pelagics fisheries competition with seabirds: Review and application
10:00	**Andrey S. Krovnin** Prospects of a new "sardine epoch" in the Northwest Pacific	**Julie A. Thayer** Predator forage needs: Comparison and synthesis of bioenergetic and numerical response models
10:20	**Marek Ostrowski** From physical mechanisms to natural fluctuations of small pelagic fishes: The Angolan upwelling scenario	**Maite Louzao** Understanding pelagic seabird 3D environment from multidisciplinary oceanographic cruises
10:40	***Coffee/Tea Break***	***Coffee/Tea Break***
11:00	**Andreia V. Silva** Patterns in chub mackerel abundance and distribution in relation to environmental conditions	**Laura Wise** Portuguese purse seine fishery spatio-temporal overlap with top predators
11:20	**Najib Charouki** Spatial time series analysis of the small pelagic fish on the shelf north of Cap Blanc within its upwelling ecosystem	**Róisín Pinfield** Biology and ecology of killer whales (*Orcinus orca*) foraging around pelagic trawlers in the northeast Atlantic
11:40	**Alexandra Silva** Demographic connectivity of sardine in the Bay of Biscay and Iberian coast region	**Anders Frugård Opdal** Unclear associations between pelagic fish and jellyfish in four major marine ecosystems
12:00	**Timothée Brochier** Population traits in small pelagic fish model: Emergence from interactions between a turbulent upwelling environment and individual behaviors in upwelling systems	**Richard D. Brodeur** Predation impact by juvenile salmon on early life stages of anchovy in the eastern North Pacific Ocean
12:20	**Concluding remarks by Convenors**	**Concluding remarks by Convenors**
12:30	**Session 1 ends**	**Session 3 ends**

Schedule at a Glance, March 10

Plenary

14:00 **Session Summaries and General Discussion**

Ryan Rykaczewski (S1)

Susana Garrido (S2)

Arnaud Bertrand (S3)

Coffee/Tea Break

James Ianelli (S4)

Merete Tandstad (S5)

Maroes Kraan/Yoshioki Oozeki (S6)

17:00 **Closing Ceremony and Presentation of Awards**

Schedule at a Glance, March 11

W1 (Saanich 1 Room) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context*		**W2 (Oak Bay 1 Room)** *Methods and techniques for sampling and assessing small pelagic fish populations*	
9:00	**Introduction by Convenors**	9:00	**Introduction by Convenors**
		9:10	**Timothy Essington (Invited)** Delayed detection of productivity declines amplifies forage fish population collapses
9:20	Statistical aspects **Roy Mendelssohn (Invited)** Easy access to environmental data for analyzing environmental drivers of the dynamics of small pelagic fish		
		9:30	**Sherri C. Dressel and Jaclyn S. Cleary** Assessment of Pacific herring (*Clupea pallasii*) populations in the northeast Pacific Ocean
		9:40	**Andrés Uriarte** BIOMAN: Anchovy DEPM surveys in the Bay of Biscay from 1987 to 2016
		9:50	**Matt Wilson** Recruitment Processes Alliance research on age-0 juvenile Walleye Pollock in the Gulf of Alaska and eastern Bering Sea
10:00	Impact of decadal and multi-decadal climate variability, large-scale current changes and fishing	10:00	**Leandra de Sousa** Methods and techniques for sampling and assessing Arctic Cod in the Chukchi Sea
		10:10	Brief overviews on sampling programs/assessments
10:40	***Coffee/Tea Break***	10:40	***Coffee/Tea Break***
11:00	Impact of decadal and multi-decadal climate variability, large-scale current changes and fishing (*cont.*)	11:00	Discussion and Summary
11:30	Break-out groups		
12:20	***Lunch***		
		12:30	**Workshop 2 ends**

Schedule at a Glance, March 11

W4 (Esquimalt Room) *Modeling migratory fish behavior and distribution*		**W6 (Oak Bay 2 Room)** *Remote sensing and ecology of small pelagics*	
9:00	**Introduction by Convenors**		
9:10	**Akinori Takasuka (Invited)** Reaching consensus on the growth–survival paradigm in early life stages of fish		
		9:30	**Introduction by Convenors**
		9:40	**Daniel Pauly (Invited)** Mapping small pelagics, fisheries and the primary production they require
9:50	**Geir Huse (Invited)** Individual based modeling of fish migration and distribution		
		10:20	**Grinson George** Inter-annual variability in *Sardinella longiceps* in response to ENSO event in the coastal waters of India
10:30	***Coffee/Tea Break***		
		10:40	***Coffee/Tea Break***
10:50	**Hitomi Oyaizu** Modeling effects of weight and growth rate on the recruitment variability of Pacific saury (*Cololabis saira*)		
		11:00	**Renato A. Quiñones (Invited)** Inter-annual variability of upwelling, nutrients and planktonic community net metabolism in the southern Humboldt Current System: Management implications for pelagic fisheries
11:10	**Shin-ichi Ito** Challenges for modeling migratory fish behavior and distribution: An example in the western North Pacific		
11:30	Discussion		
		11:40	Discussion: Developing a remote sensing and fisheries community
12:30	**Workshop 4 ends**	12:30	***Lunch***

Schedule at a Glance, March 11 (cont.)

W1 (cont.) (Saanich 1 Room) *Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context*		**W7 (Oak Bay 1 Room)** *Simulation approaches of forage fish populations for management strategy evaluations*	
14:00	Fish scale records	14:00	Workshop overview, scope, and purpose Talks on simulation methods (15 mins each)
		14:15	**André E. Punt (Invited)** Characterizing small pelagic fishes in management simulations: Examples from the US West Coast and South Africa
14:30	Hypotheses on (i) synchrony of small pelagic populations in different ecosystems and (ii) anchovy/sardine alternations	14:30	**Nis S. Jacobsen (Invited)** Predicting temporal mortality changes from size structure
		14:45	**Jin Gao (Invited)** Simulating forage fish dynamics for MSE: A nonlinear forecasting perspective
		15:00	Breakout discussion (small groups)
15:40	***Coffee/Tea Break***		
16:00	Impact of climate change, projections, forecasts, future states	16:00	***Coffee/Tea Break***
		16:20	Groups report back to whole workshop; further discussion
16:40	Break-out groups		
		17:20	Concluding remarks by Convenors
17:40	Wrapping-up, publications	17:30	**Workshop 7 ends**
18:00	**Workshop 1 ends**		

Schedule at a Glance, March 11 (cont.)

W5 (Esquimalt Room) *Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies*		**W6 (Oak Bay 2 Room)** *Remote sensing and ecology of small pelagics*	
14:00	**Introduction by Convenors**	14:00	**Jose A. Fernandes (Invited)** Prediction of species distribution and abundance using high quality satellite products in combination with Bayesian networks
14:05	**Martin Hurret (Invited)** **(*by Pierre Petitgas*)** Bioenergetics modelling to advance knowledge on life history traits and population dynamics of small pelagic fish: Illustration with anchovy and sardine in the Bay of Biscay and beyond		
14:40	**Paul Gatti** Calibration of the DEB model for small pelagics. What data is needed and at which timescale?	14:40	**Nandini Menon N** Application of phytoplankton biomass as an aid in management of marine resources of the southeastern Arabian Sea
14:55	**Eneko Bachiller** Bioenergetics modeling of the annual consumption of zooplankton by pelagic fish feeding in the Norwegian Sea		
15:10	**Laure Pecquerie** Combining lab and bioenergetic modelling approaches to better reconstruct growth from otoliths of *Sardina pilchardus* larvae	15:00	***Coffee/Tea Break***
15:25	**Myron Peck** Ecophysiological models of foraging and growth of small pelagic fish: Progress and challenges	15:20	Discussion: Planing for a symposium on remote sensing and fisheries
15:40	***Coffee/Tea Break***		
16:00	Discussion / data overview / manuscript planning DEB Growth allocation modelling Stage-specific Ecophysiology Review	16:20	Concluding remarks by Convenors
17:10	Final summary – next steps (report/work/ publication(s))	16:30	**Workshop 6 ends**
17:30	**Workshop 5 ends**		

POSTERS

SESSION 1: Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

S1-P1 **Kinsey Frick**
Spatial and temporal variability in nearshore forage fish communities in the Strait of Juan de Fuca

S1-P2 (*cancelled*) **Anna N. Kagley**
Nearshore forage fish populations in the context of Elwha River dam removals

S1-P3 **Alba Jurado-Ruzafa (*by M. Teresa García Santamaría*)**
Seasonal evolution of oceanographic parameters in relation to *Trachurus picturatus* landings index in Tenerife (the Canary Islands, Spain)

S1-P4 **Eleuterio Yáñez**
Climate change and pelagic fisheries predictions in Chile (CLIPESCA)

S1-P5 (*cancelled*) **Anthony B. Ndah**
Multi-temporal Analysis of Upwelling/Downwelling Dynamics in the South China Sea and potential implications for coastal fisheries

S1-P6 **Josephine Dianne L. Deauna**
The effect of wind strength and variability on the Dipolog–Sindangan Bay upwelling system, Philippines

S1-P7 **José Carlos Báez (*by M. Teresa García Santamaría*)**
Influence of the climatic oscillations on the sardine off Northwest Africa during the period 1976-2014

S1-P8 (*cancelled*) **Fatima Whabi**
Age and growth of Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758) in Morocco's Atlantic region

S1-P9 **Guðmundur J. Óskarsson**
Quantification and causes of two incidents of fish kill of Icelandic summer-spawning herring (*Clupea harengus*) in the winter 2012/2013

S1-P10 **Christina Bourne**
Using otolith shape analysis to quantify changes in stock distribution and migration of Atlantic herring in Newfoundland

S1-P11 **Alba Jurado-Ruzafa (*by M. Teresa García Santamaría*)**
Seasonal evolution of oceanographic parameters in relation to small pelagic fish landings index in the Canary Islands (Spain) from 2009 to 2015

S1-P12 (*cancelled*) **Athanassios C. Tsikliras**
Synchronization of the mean temperature of the pelagic catch (MTpC) with North Atlantic climate variability

S1-P13 **Dorothee Moll**
Estimating the contribution of single nursery areas to the overall herring (*Clupea harengu*s) population in the western Baltic Sea by otolith chemistry

S1-P14 **Vanessa Izquierdo-Peña**
Geographic detection of the Regime signature

S1-P15 **Fran Mowbray**
Distribution shifts of capelin (*Mallotus villosus*) and arctic cod (*Boreogadus saida*) in the Northwest Atlantic and consequences for regional productivity

S1-P16 (*March 10, talk, 11:40*) **Alexandra Silva**
Demographic connectivity of sardine in the Bay of Biscay and Iberian coast region

S1-P17 **Ian S.F. Jones**
Enhancing the pelagic fish catch in regions adjacent to ocean upwelling fisheries

S1-P18 **Gertrudes Luque**
Spatial and temporal variability of the North Humboldt Current System upwelling front and its influence on small pelagic resources distribution

S1-P19 **Jose A. Valencia-Gasti**
The sardine population in northwestern Mexico: Current state

S1-P20 **Sourav Maity**
Categorizing ecological indicators for predicting Hilsa shad (*Tenualosa Ilisha*) abundance in northern Bay of Bengal

S1-P21 **Elena Ustinova (*by Svetlana Naydenko*)**
Oceanographic conditions and spatial distribution, migration patterns and fishing grounds for saury, sardine and mackerels in the Northwest Pacific

S1-P22 **Omar Ettahiri (*by Najib Charouki*)**
Spatial patterns diversity of copepods under coastal upwelling variability off North West African Ecosystem

S1-P23 (*cancelled*) **Santiago Montealegre-Quijano**
Drivers of inter-anual variability in the abundance of the Broadband Anchovy *Anchoviella lepidentostole* in Southeast Brazil

S1-P24 (*March 8, talk, 12:00*) **Miguel Ñiquen**
Size structure based associations between anchoveta and other pelagic resources in Peruvian waters

S1-P25 **Kirstin Holsman**
Evaluating spatial patterns in foraging landscapes and energetics; (part 2) modeling projections for pollock under future scenarios.

S1-P26 (*cancelled*) **Elizabeth Siddon**
Evaluating spatial patterns in foraging landscapes and energetics (part 1): empirical observations for pollock across a long-term time series from the eastern Bering Sea

SESSION 2: External drivers of change in early life history, growth and recruitment processes of small pelagic fish

S2-P1 **Matt Wilson**
Geographic and temporal variation in elemental composition of age-0 walleye pollock (*Gadus chalcogrammus*) otoliths in the western Gulf of Alaska, September 2007 and 2011

S2-P2 (*March 8, talk, 15:00*) **W. Scott Pegau**
(Poster & Talk)
Herring research and monitoring in Prince William Sound, Alaska

S2-P3 **Yasuhiro Kamimura**
Effects of density dependence in growth and condition factor on pre-recruit chub mackerel *Scomber japonicus*

S2-P4 **Marta Albo-Puigserver**
Bioenergetics of European sardine: simulating environmental influences on population dynamics in the western Mediterranean Sea

S2-P5 **Fletcher Sewall**
Empirically-based models of oceanographic and biological influences on Pacific Herring recruitment in Prince William Sound

S2-P6 **Alexanra A. Bagarinao**
Inter-annual variability in early life growth of the Bali sardine, *Sardinella lemuru*, caught off the northern Zamboanga Peninsula and the role of environmental factors

S2-P7 **Francisco Cerna**
Testing the growth-survival relationship in the anchovy (*Engraulis ringens*) in northern Chile

S2-P8 **Samuel Soto**
Modeling the transport of eggs and larvae of anchoveta (*Engraulis ringens*) during the spawning season in the inland sea of Chiloé, Northern Patagonia

S2-P9 **Sara Malavolti**
Distribution of European anchovy, *Engraulis encrasicolus*, eggs and larvae in relation to environmental conditions in the south-western Adriatic Sea

S2-P10 **Jorge Castillo**
Environmental conditions for anchovy and common sardine recruitment in central-southern Chile (33°-40°S) between 1987 and 2013

S2-P11 (*cancelled*) **Moagabo Natalie Ragoasha**
The interannual and intraseasonal variability of Lagrangian transport in the southern Benguela

S2-P12 **Hitomi Oyaizu**
Modeling effects of weight and growth rate on the recruitment variability of Pacific saury (*Cololabis saira*)

S2-P13 **Brian P.V. Hunt**
Comparison of muscle and scale isotope signatures of Pacific Herring (*Clupea pallasii*), and their application in regional life history studies in British Columbia (Canada)

S2-P14 **Brendan D. Turley**
Reconsidering evidence for the optimal environmental window in the southern Benguela

S2-P15 (*cancelled*) **Khadija Amenzoui**
Reproduction, age and condition factor (K) of *Sardina pilchardus* (Walbaum, 1792) in the Atlantic Moroccan

S2-P16 **S. M. Nurul Amin**
Population Dynamics of Devis' Anchovy, *Encrasicholina devisi* (Whitley, 1940) in Pitas Waters of Marudu Bay, Sabah, Malaysia

S2-P17 **Hannah Murphy**
A re-evaluation of the drivers of recruitment variability in capelin (*Mallotus villosus*)

S2-P18 **Enrique Gonzalez-Ortegon (*by Francisco Baldó*)**
Modelling the effect of environmental and anthropogenic factors on the abundance of early life-history stages of the European sardine in the Guadalquivir estuary

SESSION 3: The role of small pelagic fish in food web dynamics between plankton and top predators

S3-P1 **Svetlana Naydenko**
Food web changes in epipelagic nektonic communities of the Northwest Pacific

S3-P2 **Joanna Calkiewicz**
Zooplankton Mean Size and Total Stock (MSTS) indicator applied for testing the feeding conditions of small pelagic fish in the southern Baltic Sea

S3-P3 **José-María Quintanilla**
Diel variability of the diet of *Sardina pilchardus* larvae in Málaga Bay (Alboran Sea, SW Mediterranean)

S3-P4 **Marta Albo-Puigserver**
Colonizing new habitats and meeting new neighbors: trophic relationships between the expanding round sardinella and coexisting small pelagic fish in the NW Mediterranean Sea

S3-P5 **Yunrong Yan**
Function of the small pelagic fishes in the marine food web dynamics of the Beibu Gulf, South China Sea

S3-P6 **Claudia Günther**
Temperature and size-dependent functional response of *Sprattus sprattus* L.

S3-P7 **Shingo Watari**
Ecosystem modeling in the western North Pacific with a focus on small pelagic fish

S3-P8 **Mayumi Arimitsu**
Jellyfish blooms in warm water may signal trouble for forage fish in a warming climate

S3-P9 **John Moran**
Humpback whales ruin a perfectly good overwintering strategy for Pacific herring in Alaska

S3-P10 **Alexandra Silva**
The role of small pelagic fish in the western Iberian upwelling ecosystem

S3-P11 **Aida Sartimbul**
Seasonal variation of Omega-3 content from Bali Sardines catch in Bali Strait and its drivers

S3-P12 **Tore Johannessen**
Predator-prey synergism – A novel perspective in ecology

S3-P13 (*cancelled*) **Julie A. Thayer**
Are Northern Anchovy Caught in a "Predator Pit"?

S3-P14 (*March 9, talk, 16:40*) **James J. Ruzicka**
(Poster & Talk)
Do jellyfish blooms affect small pelagic fishes in coastal marine environments?:
A comparative analysis of three coastal ecosystems

S3-P15 **Leandra Sousa**
The role of prey selectivity in shaping Arctic Cod distribution in the Chukchi Sea

SESSION 4: Comparison of methods for assessment of small pelagic fish populations

S4-P1 **Martin Huret (*by Pierre Petitgas*)**
Estimation of total egg production from CUFES data and comparison with acoustics: an example with anchovy and sardine in the Bay of Biscay

S4-P2 **Aida Sartimbul**
Morphology, meristic, and genetic approach for *Sardinella lemuru* migration in Bali Strait and South Java

S4-P3 (*cancelled*) **Santiago Montealegre-Quijano**
Reproductive biology, population dynamics and fishing of the Broadband Anchovy (*Anchoviella lepidentostole*) in Southeast Brazil

S4-P4 **Oleg Kruchinin (*by Svetlana Naydenko*)**
Technique for assessment of saury concentration in the lighted area

SESSION 5: Future challenges for ecosystem-based management of highly variable fish populations

S5-P1 **Marta Albo-Puigserver**
Who did it?: Assessing potential pressures on small pelagic fish populations of the NW Mediterranean Sea using a qualitative modelling approach

S5-P2 **Aziza Lakhnigue**
Atlantic small pelagic resources in Morocco: which place in the north-west african sub-region?

SESSION 6: Small pelagic fish and humans – Social, economic and institutional dimensions

S6-P1 **Dmytro Khrystenko**
Stocks, harvest and potential use of Black and Caspian Sea sprat Clupeonella cultriventris in the Dnieper River Basin, Ukraine

S6-P2 **Manuel Muntoni**
Small vs Big: Lessons from small-scale small pelagic fisheries facing global changes

S6-P3 **Luis Gallardo**
Growth opportunities for artisanal fisheries in México

S6-P4 **Aurelie Cosandey-Godin**
How well does Canada manage forage fish fisheries?

S6-P5 **Asuncion B. De Guzman**
Interannual Variability in Sardine Fisheries in the Northern Zamboanga Peninsula, Philippines: Understanding Human-Environment Synergy in Sustainable Fisheries Management

WORKSHOP 5: Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies

W5-P1 **Shin-ichi Ito**
Biological parameter estimation for a bioenergetics model of chub mackerel (*Scomber japonicus*)

Sessions and Workshops Descriptions

S1: Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

Convenors:
Emanuele Di Lorenzo (Georgia Institute of Technology, USA)
Dimitri Gutierrez (IMARPE, Peru)
Svein Sundby (Institute of Marine Research, Norway)
Yongjun Tian (Ocean University of China, China)

Plenary Speaker:
David Field (Hawai'i Pacific University, USA)

Invited Speaker:
Bryan Black (University of Texas at Austin, USA)

Planktivorous small pelagic fish (SPF) species demonstrate specific patterns of behavior and growth dynamics different from higher trophic level species. First, they are more volatile in their spatial distributions and may, to a larger extent than demersal and piscivorous fish species, exceed typically defined boundaries of Large Marine Ecosystems (LMEs) with respect to both feeding areas and spawning areas. Second, they display particularly large temporal variability in their abundances on interannual to decadal and multi-decadal scales when they can oscillate between close to extinct populations and extremely high abundances. These features seem independent of the structure and function of the particular ecosystem which they inhabit, and have also occurred historically and prior to the increase in fishing pressure that developed during the second half of the 20th century. We see such attributes in the large eastern boundary upwelling ecosystems as well as in high-latitude spring-bloom ecosystems from temperate regions to the Arctic. These responses indicate that SPF populations might be more sensitive to environmental variability than other fishes, although the kind of environmental variability differs considerably among the various ecosystems. Climate variability on decadal to multi-decadal scales caused, for example, by ENSO, NAO, AMO or PDO, seems to be an important factor influencing large-scale population fluctuations and migrations as demonstrated by observations sometimes stretching over centuries. Alternating sardine- or anchovy-dominated ecosystems separated by regime shifts also occur when the species composition of the pelagic zone changes substantially. One unresolved question is whether there is synchrony between the abundance swings of small pelagic fish populations in different ecosystems that are sometimes separated by thousands of kilometers or even by continents.

In this session, we invite papers that describe and analyze the linkages between environmental variability and change and fluctuations in abundance, distribution and migration of pelagic fish species. Papers on different ecosystems as well as on comparative analyses among ecosystems and populations are welcome. Of special interest are papers that go beyond correlations and address possible mechanistic links, particularly where climate change impacts can be addressed.

S2: External drivers of change in early life history, growth and recruitment processes of small pelagic fish

Convenors:
David Checkley (Scripps Institution of Oceanography, UCSD, USA)
Susana Garrido (Instituto Português do Mar e da Atmosfera, Portugal)
Pierre Petitgas (IFREMER, France)
Akinori Takasuka (National Research Institute of Fisheries Science, FRA, Japan)

Plenary Speaker:
Stylianos (Stelios) Somarakis (Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Greece)

Invited Speaker:
Dominique Robert (Université du Québec à Rimouski, Canada)

Small pelagic fish (SPF) populations are well known to be subject to substantial changes in abundance over relatively short time periods – so called "boom and bust" population dynamics. Their dynamics can also be modulated by a wide variety of external drivers. These can range from basin-scale, e.g., El Niño events, to global-scale changes related to climate change, but they can also be local, e.g., the loss of a particular spawning ground for herring. External drivers can include both anthropogenic factors and natural changes. The key anthropogenic driver is probably fishing pressure, not only on the small pelagic species themselves, but also on their predators and potentially, their prey. Anthropogenic drivers can include less direct effects, e.g., climate change and obstruction of migration routes. Non-anthropogenic drivers can be divided into biotic and abiotic factors. Abiotic ones include not only changes in temperature and salinity, but also changes in small- or large-scale ocean circulation affecting spawning and nursery areas. Biotic factors can principally involve the abundance, quality and availability of prey, particularly at the sensitive life history stage, e.g., as larvae. Understanding the population dynamics of the predators may also help fisheries managers to more carefully project maximum sustainable yield population and fishing mortality targets.

In this session, we invite papers that investigate the population level responses of SPF to these and other external drivers. The session is focused, in particular, on early life history stages, from eggs through to recruitment, as well as growth before and after recruitment. However, contributions on the effect of external factors on other key elements of the ecophysiology of these species are also welcome, for instance, in terms of maturity development, fecundity, etc. Priority will be given to research that shows how changes in the population dynamics of SPF can be understood in the context of the ecosystems they occupy, and how those understandings can potentially improve our ability to manage and exploit these fisheries sustainably.

S3: The role of small pelagic fish in food web dynamics between plankton and top predators

Convenors:
Arnaud Bertrand (Institut de Recherche pour le Développement, France)
Salvador Lluch-Cota (CIBNOR-CONACYT, Mexico)
William Peterson (Northwest Fisheries Science Center, NMFS, USA)

Plenary Speaker:
Sophie Bertrand (Institut de Recherche pour le Développement, France)

Invited Speaker:
Susana Garrido (Instituto Português do Mar e da Atmosfera, Portugal)

Small pelagic fish (SPF) feed on phyto- and zooplankton and are, at the same time, the main food source for many marine predators such as large fish, mammals and birds. Hence, they are important conduits of energy transfer. Because of their key position between plankton and top predators, those ecosystems in which SPF play a dominant role are called “wasp-waist” ecosystems. The overarching question of this session is: What do we know about the feeding habits of SPF on plankton and, in turn, what is known about the feeding habits of the fishes, seabirds, and mammals that feed upon SPF? To what degree are SPF and top predators selective feeders vs. generalists? Are there examples of top-down control by SPF on zooplankton and bottom-up control by SPF on top predators? How do feeding rates of predators compare to production rates of prey? Is foraging behavior of top predators influenced by the size of prey patches (or lack of patches)? What is the role of "hot spots" on foraging behavior of top predators? How are "hot spots" created and maintained? Considering multiple-scale spatial and temporal dynamics, what is known about temporal (decadal to seasonal) and spatial (meso- to micro-scale) variability in predator–prey dynamics, for example, seasonal matches or mismatches in prey production compared to when top predators migrate to an area to feed – are there times and places where the carrying capacity of the environment is exceeded due to too many predators or too few prey? How well do SPF meet the definition of the waist in a wasp-waist ecosystems? Can we identify impacts of climate change on SPF predator-prey interactions? Contributions from empirical as well as modelling studies are welcome.

S4: Comparison of methods for assessment of small pelagic fish populations

Convenors:
Miguel Bernal (FAO, General Fisheries Commission for the Mediterranean)
Jennifer Boldt (Department of Fisheries and Oceans, Canada)
Momoko Ichinokawa (National Research Institute of Fisheries Science, FRA, Japan)
Reidar Toresen (Institute of Marine Research, Norway)

Plenary Speaker:
Reidar Toresen (Institute of Marine Research, Norway)

Invited Speaker:
James Ianelli (Alaska Fisheries Science Center, NMFS/NOAA, Seattle, WA, USA)

The assessment of small pelagic fish (SPF) stocks offer a number of challenges related to the biology and ecology of this group of species. High reproductive potential and high and variable natural mortality, especially in early life stages, often imply large variability in recruitment. Together with the short life span of SPF, this means that population abundance is often largely dependent on recruitment strength and shows large fluctuations. SPF often exhibit complex migration dynamics, with different individuals having different migration capacity depending on their size and condition. In addition, SPF often demonstrate gregarious behavior which can be affected by population biomass. As the result, the availability of the individuals to the fleet changes with the abundance of the resource, creating changes in catchability which are difficult to account for. Some of these characteristics invalidate or challenge basic assumptions of assessment models commonly used for other stocks. SPF populations often show low coherence in relation to cohort abundance (the abundance of one year class and the next) and, when it exists, it is restricted to the few year classes that encompass the bulk of the fishery. Also, stock recruitment relationships are often not clear and show a large degree of autocorrelation, due to the large influence of one year recruitment in the next year biomass. Finally, it is common that there is a lack of relation (or, in some cases, an inverse relation) between catch per unit effort (CPUE) and abundance. These characteristics imply that age-structured models and medium-term predictions are often uncertain and in some cases biased. Alternative stock assessment models such as two-stage (recruits and adults) models have been attempted in several stocks, and often Bayesian methods have been used to facilitate the incorporation of uncertainty in the models. Under the uncertainties described above, the use of direct (fishery-independent) methods as tuning indexes or even as the main source for the assessment is considered crucial for a reliable stock assessment. Thus, acoustic as well as ichthyoplankton surveys have often been used to provide estimates of stock abundance, in some cases by developing specific methods such as the Daily or Annual Egg Production Method (DEPM, AEPM). In many cases indexes of next year recruitment have been attempted to facilitate short-term simulation and, therefore, management. Environmental indices and surveys of juvenile abundance are commonly used as advance indicators of recruitment strength in several stocks, although examples of misleading signals from these indices exist, and a consolidated time series together with some validation of the observed index is often required before it can be used for stock assessment and management purposes.

In this session, we invite papers covering all aspects related to the assessment of status of small pelagic stocks, as well as on short- and medium-term simulation of stock abundance, using any kind of indicator of future recruitment (from assumptions to environmental indices to juvenile surveys) and natural mortality. Discussion on benefits of different approaches to the assessment of stocks is expected.

S5: Future challenges for ecosystem-based management of highly variable fish populations

Convenors:
Warrick (Rick) Fletcher (Department of Fisheries, WA, Australia)
David Reid (Irish Marine Institute, Ireland)
Merete Tandstad (FAO Fisheries and Aquaculture Department)
Andres Uriarte (AZTI, Spain)

Plenary Speaker:
Kwame Koranteng (EAF-Nansen Project, FAO)

Invited Speaker:
Verena Trenkel (IFREMER, France)

Ecosystem based management of small pelagic fish (SPF), while presenting many of the same problems that exist in demersal fisheries also has additional issues specific to SPF species. Most obvious among these are issues raised by the tendency of SPF to “boom and bust” stock dynamics, and to the often large migrations undertaken by these species. There are also often substantial changes in spawning and recruitment that are modulated by environmental processes, including upwelling and other oceanographic processes, that need to be taken into account in the management to assist the significant economic and social systems these fisheries often support. It can be argued that what fisheries for SPF needs the most is to take account of environmental processes directly in assessment, and particularly in stock projections, but this means that we need to be able to establish these relationships with sufficient accuracy to be used in assessment models. An additional issue is that many SPF species are very short lived (e.g., sandeels and anchovy) and can often be subject to predominantly “recruit” fisheries. This puts a premium on management at a short time scale, i.e., in the year of assessment.

The role of many SPF as “forage fish” also requires different approaches to management. There is often a need to consider the requirement from these stocks of biomass to support higher trophic levels, including other commercial species, emphasizing the ecosystem support “goods and services” aspect of these species. While SPF often represent a valuable catch in themselves, they may also underpin the productivity of the potentially more valuable higher trophic level stocks. Indeed they may be an important prerequisite for some of those stocks to be able to be exploited at maximum sustainable yield. All these issues represent challenges to management. In particular, the strong links between SPF and their environment and their role as forage fish makes them strong candidates for an Ecosystem Approach to Fisheries Management (EAFM). Most importantly, management needs to consider both the effects of ecosystem processes on stock productivity, and the combination of that productivity and exploitation on the rest of the ecosystem. The wide geographical range of SPF stocks, and their often substantial migrations, raises other issues for management that are less common in demersal fisheries, in particular when the distributions in space and time overlap many jurisdictions.

In this session, we invite papers on all aspects of management that focus on the specifics of SPF species. These can cover SPF fisheries ranging from full-scale industrial fisheries to small-scale or artisanal fisheries. In particular, we encourage contributions on: (i) the inclusion of ecosystem elements directly in assessment and management; (ii) the management of short-lived species and recruit-based fisheries, especially in the context of minimizing the impacts on social and economic systems; (iii) the management of SPF species in the context of their role as "forage fish" and their role in the food web; and (iv) cross-jurisdictional management in the context of wide distributions and substantial migrations.

S6: Small pelagic fish and humans – Social, economic and institutional dimensions

Convenors:
Manuel Barange (FAO, Fisheries and Aquaculture Policy and Resources Division)
Marloes Kraan (IMARES, The Netherlands)
Mitsutaku Makino (Fisheries Research Agency, Japan)
Jörn Schmidt (University of Kiel, Germany)
Rashid Sumaila (Fisheries Centre, University of British Columbia, Canada)

Plenary Speaker:
Ratana Chuenpagdee (Memorial University, Canada)

Invited Speaker:
Manuel Barange (Fisheries and Aquaculture Policy and Resources Division, FAO)

Small pelagic fish (SPF) fisheries have a high economic value because of their use for human consumption and production of fish meal and fish oil, and their pivotal role in sustaining fisheries for large predators. They are significant in terms of future global food security, particularly for the economy, diet and livelihoods of communities in the developing world, and for the well-being of villages, regions and even entire countries. In many parts of the world these fisheries have a significant history, with century-old techniques, norms, cultural practices and values. As SPF are exploited by small-scale as well as industrial fisheries, a balance has to be kept between both sectors. A third of global fisheries production, mainly from SPF, is used to produce the largest marine-based commodity, fish meal and oil, and the fishery for Peruvian anchovy alone contributes about 50% of the global total. Aquaculture, the fastest growing food production system worldwide, utilizes about 70% and 90% of fish meal and fish oil production, respectively, exerting a growing pressure on SPF fisheries. At the same time, SPF fisheries are variable and at the mercy of environmental and climate variability and change, which pose pressure and challenges to their management. Governance poses an additional challenge as SPF are migratory and are often shared stocks, asking for regional governance instead of the more common national management.

In this session, papers are invited on a large range of socio-economic and institutional topics which include: (i) food security and nutrition, (ii) governance, (iii) institutional analysis, (iv) economic viability analysis, (v) social and economic consequences of the impacts of climate change on SPF, (vi) analysis of fisheries policies, (vii) livelihoods, (viii) SPF culture, (ix) Social-Ecological Systems approach, (x) capacity building for global changes, (xi) traditional and cultural value, (xii) resilience of coastal communities, (xiii) utilization of pelagic fish resources, and (xiv) conflict.

W1: Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context

Convenors:
Jürgen Alheit (Germany)
Emanuele Di Lorenzo (Georgia Institute of Technology, USA)
Ryan Rykaczewski (University of South Carolina, USA)
Svein Sundby (Institute of Marine Research, Norway)

Invited Speaker:
Roy Mendelssohn (Pacific Fisheries Environmental Laboratory, NOAA/NMFS/SWFSC, USA)

This 1-day workshop is intended to facilitate continued discussion of the topics raised in Session 1 of the symposium.

Planktivorous small pelagic fish (SPF) species demonstrate characteristic patterns of behavior and growth dynamics distinguishable from those of higher trophic level species. First, they are more volatile in their spatial distributions and may, to a larger extent than demersal and piscivorous fish species, exceed typically defined boundaries of Large Marine Ecosystems with respect to both feeding areas and spawning areas. Second, they display particularly large temporal variability in their abundances on interannual to decadal and multi-decadal scales when they can oscillate between nearly extinct populations to extremely high abundances. These features seem independent of the structure and function of the particular ecosystem which they inhabit and have also occurred historically and prior to the increase in fishing pressure that developed during the second half of the 20th century. We see such attributes in the large eastern boundary upwelling ecosystems as well as in high-latitude spring-bloom ecosystems from temperate regions to the Arctic. These responses indicate that SPF populations might be more sensitive to environmental variability than other fishes, although the kind of environmental variability differs considerably between the various ecosystems. Climate variability on decadal to multi-decadal scales caused, for example, by ENSO, NAO, AMO or PDO, seems to be an important factor influencing large-scale population fluctuations and migrations as demonstrated by observations sometimes stretching over centuries. Alternating sardine- or anchovy-dominated ecosystems separated by regime shifts seem to co-occur with substantial changes in the species composition of the pelagic zone. One critical, yet unsolved question is whether there is synchrony among the abundance swings of SPF populations in different ecosystems sometimes separated by thousands of miles or even continents.

The anticipated outcomes include: (1) a workshop report, (2) a summary paper and (3) a special issue of a peer-reviewed journal (with manuscripts based on Session 1 presentations).

W2: Methods and techniques for sampling and assessing small pelagic fish populations

Convenors:
Jennifer Boldt (Department of Fisheries and Oceans, Canada)
Matthew Baker (North Pacific Research Board, USA)
Miguel Bernal (FAO, General Fisheries Commission for the Mediterranean)
Stylianos (Stelios) Somarakis (Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Greece)

Invited Speaker:
Timothy Essington (SAFS, University of Washington, USA)

Small pelagic fish (SPF) are essential prey species for a variety of predators and can also be culturally, commercially, and recreationally important. The abundance of SPF populations is highly variable both in space and time, attributes which complicate sampling, forecasts and retrospective analyses related to recruitment. Population abundance is affected by environmental conditions, system productivity, and the carrying capacity of the ecosystem, as well as by a variety of factors influencing survival and recruitment to the adult population. Understanding what factors affect the abundance, recruitment, age structure, size, condition, and distribution of SPF presents a challenge to the assessment of these species. Increased attention has been paid to the importance of pelagic fishes and the need understand their dynamics and responses to environmental conditions and their role within trophic food webs and ecosystems. Surveys and assessments for some stocks and species are often undeveloped, and important life history attributes remain unknown. Improved information on SPF is required to characterize their role in the ecosystem and advance both species-specific assessments as well as ecosystem models.

The goals this 0.5-day workshop are to: (1) identify and compare the efficacy of various survey assessment methods, and how to incorporate survey information into modeled assessments, and (2) pinpoint ongoing surveys and information for pelagic fishes and to discuss opportunities for sharing data, technologies, and advancing survey and assessment efforts directed towards these fish. Workshop participants will discuss the following topics:

Comparisons of field sampling techniques, including acoustics, biological sampling, net sampling, and alternate techniques;

How best to integrate estimates of abundance, distribution, recruitment, etc. into stock assessment models. The idea will be to openly discuss how to incorporate any information useful for assessment (not only abundance indexes) into models (not necessarily traditional stock assessment models) that could be useful to assess the status of the stocks.

Archiving of current state of knowledge on abundance, age structure, life history attributes, and distribution for a variety of important pelagic fish species.

The workshop format will include presentations and a discussion. There will be one or two keynote speakers and several brief presentations (5-10 minutes each), followed by a discussion. For the brief presentations, we invite papers on the topics listed above. Prior to the workshop, speakers will be asked to address in their presentations pre-defined questions that will lead to and facilitate discussion. After the workshop, participants are encouraged to attend the W7 workshop, as this is a continuation of the theme in the W2 workshop.

W4: Modeling migratory fish behavior and distribution

Convenors:
Shin-ichi Ito (AORI, University of Tokyo, Japan)
Enrique Curchitser (Rutgers University, USA)

Invited Speakers:
Geir Huse (Institute of Marine Science, Norway)
Akinori Takasuka (National Research Institute of Fisheries Science, FRA, Japan)

Recent improvements in ocean model spatial resolution and data assimilation techniques have enabled more realistic simulations of larval fish transport and distributions (e.g., Ospina-Alvarez et al., 2015). Full life-cycle migratory fish models have also been developed using high-resolution circulation models (e.g., Rose et al., 2015; Fiechter et al., 2015). However, knowledge gaps in the behavior of migratory fish limits our ability to improve their simulation. Fish behavior is a consequence of genetics, environmental responses, prey availability, competition and interaction with other species, predator avoidance, maturity and learned behavior. All these factors lead to complex behavior patterns. Enhancements in remote sensing, modeling techniques, tagging technologies for fish, otolith and genetic analyses are contributing to our understanding of fish migration patterns.

The purpose of this 0.5-day workshop is to synthesize the current state-of-the-science in modeling of migratory fish behavior and their spatial distribution and to identify remaining challenges. Presentations are encouraged to discuss successes and failures in the modeling of migratory fish. Papers related to data availability to evaluate fish behavior models as well as laboratory and experimental approaches are desired. The anticipated outcomes include: (1) a workshop report, (2) a white paper on the challenges of migratory fish modeling and (3) a peer-reviewed manuscript, if sufficient new ideas emerge.

W5: Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies

Convenors:
Myron Peck (University of Hamburg, Germany)
Kirstin Holsman (AFSC, NOAA-Fisheries, USA)
Shin-ichi Ito (AORI, University of Tokyo, Japan)
Laure Pecquerie (IRD, France)

Invited Speaker:
Martin Huret (IFREMER, France)
Pierre Petitgas will deliver the talk on behalf of Martin Huret

Large fluctuations and oscillations in small pelagic fishes (SPF) appear governed by changes in a variety of extrinsic (environmental) factors causing species-specific differences in growth and survival. These patterns arise, in part, due to intrinsic (ecophysiological) differences among species. Given the strong link between the productivity of SPF and changes in bottom-up forcing, advancing knowledge on species-specific differences in growth physiology and bioenergetics will greatly advance a cause-and-effect understanding of the mechanisms underlying changes in the distribution, reproduction, and growth of these fishes (Peck et al. 2013). Importantly, this ecophysiological knowledge can be used to parameterize mechanistic foraging and growth models to project how the distribution and productivity of species may be altered in a future climate (Hollowed et al. 2009, Pörtner and Peck 2010). A key step to projecting climate impacts is to clarify the relationship between temperature and dynamic rates that structure trophic interactions (Kristiansen et al. 2007, Hollowed et al. 2009, Rijnsdorp et al. 2009).

Recent advances have occurred in laboratory, field and modelling studies on SPF which need to be discussed, compared and integrated. For example, successful (re-) emphasis on maintaining small pelagic brood stocks has promoted new laboratory research on larvae (e.g., European sardine - Caldeira et al. 2015, Garrido et al. 2015). At the same time, individual-based, mass-balance, and ecosystem/food-web models are continually being improved and now provide a suite of modeling frameworks for projecting climate-driven changes in the distribution, productivity, and trophic interactions of small pelagic fishes. For example, Dynamic Energy Budget (DEB) models have been created to include additional aspects of life history strategy such as changes in allocation to growth and/or reproduction in response to changes in key environmental features. These physiology-based models can inform advice on the management of small pelagic fishes and their habitats under future climate change if outputs can be incorporated in management models and frameworks.

This 0.5-day workshop will focus on:

physiological responses of SPF to climate-driven abiotic factors and quantitative, life-stage specific comparison of well-studied species;

existing datasets and parameterization for bioenergetics modeling of growth, foraging and movement;

data needs for bioenergetics-based modeling approaches to better project the distribution, foraging and growth of small pelagic fishes.

The expected outcomes include: (1) a workshop report and (2) a review paper and/or themed set of articles discussing:

recent advances in understanding of foraging and growth dynamics in SPF;
comparison of ecophysiological thresholds for feeding, growth, survival;
environmental controls on the allocation of energy to reproduction;
emerging research needs to enhance our capacity to project population dynamics.

W6: Remote sensing and ecology of small pelagics

Convenors:
Shubha Sathyendranath (Plymouth Marine Laboratory, UK)
Grinson George (Central Marine Fisheries Research Institute, India)
Nandini Menon (Nansen Environmental Research Centre India, India)
Trevor Platt (Plymouth Marine Laboratory, UK)

Invited Speakers:
Jose A. Fernandes Plymouth Marine Laboratory, UK)
Daniel Pauly (Institute for the Oceans and Fisheries, UBC, Canada)
Renato Quinoñes University of Concepcion, Chile)

Various remote-sensing methods have been proposed to understand variability in harvest fisheries, to improve catch per unit effort, and to explore potential impacts of climate change on future fisheries (Fernandes et al. 2015). Remote sensing applications include potential fishing zone advisories; studies to understand the link between phytoplankton phenology and fisheries recruitment (testing the match-mismatch hypothesis of Hjort-Cushing) (Platt et al. 2003; Koeller et al. 2009) and links between phytoplankton community structure and fisheries. One may anticipate that such applications would work best for small pelagics, because of the shorter interval between the trophic level of remote-sensing observations (phytoplankton) and the fisheries, and also because of the shorter time scales involved.

This 1-day workshop is designed to:

discuss recent progress in the use of satellite data to improve our knowledge of fisheries variability;
explore the use of satellite data to improve fisheries models;
investigate the use of satellite data to improve fisheries management;
investigate the use of satellite data for high seas governance of fisheries;
assess the use of remote sensing in socio-economic studies related to fisheries fluctuations; and
plan a symposium on the topic of remote sensing and fisheries.

In 2010, India hosted the first symposium on “Societal Applications in Fisheries and Aquaculture using Remotely-sensed Imagery (SAFARI)”. Selected papers from the symposium were published subsequently as a special issue of the ICES Journal of Marine Science (Stuart et al. 2011). India is now in the initial stages of planning a second SAFARI symposium in the last semester of 2017. The workshop will serve as a precursor to the second SAFARI symposium, and help plan it.

W7: Simulation approaches of forage fish populations for management strategy evaluations

Convenors:
Margaret Siple (University of Washington, USA)
Laura Koehn (University of Washington, USA)

Invited Speakers:
Jin Gao (NOAA Northwest Fisheries Sciences Center / University of Washington, USA)
Nis Sand Jacobsen (University of Washington, USA)
André Punt (University of Washington, USA)

Simulation approaches like management strategy evaluation are useful for testing harvest control rules on forage species, but these methods are hampered by a lack of information about forage fish dynamics. They may be improved, however, by incorporating data from other ecosystem components. For example, realistic dynamics for forage fish in the Pacific may be generated by incorporating oceanographic variables like temperature or food availability (Lindegren et al. 2013), catches, or predator indicators, or they may benefit from the use of time series approaches like non-linear forecasting (Sugihara 1994). Additionally, data availability and ecosystem function of small pelagic fish (SPF) are likely to vary across the Pacific.

This 0.5-day workshop will solicit input from experts in forage fish oceanography, ecology, and stock assessment and attempt to address the following questions: (1) What processes can be/should be used to generate realistic SPF population fluctuations over time within simulations? and (2) How does the importance of these variables and our ability to incorporate them in simulation models vary among the ecosystems where SPFs occur (Kuroshio/Oyashio Currents, Humboldt Current, and California Current)? Through group discussion, we plan to develop a set of guidelines for simulating realistic forage fish dynamics for different locations and life history types, which can be used by managers and ecologists to test harvest strategies. Other anticipated outcomes are: a workshop report to be distributed to PICES and ICES and a review paper discussing the simulation approaches currently in use and the challenges management strategy evaluation for small pelagics.

Abstracts
Oral Presentations

Plenary Talks

March 6

March 6, 9:30 (General Plenary-11712)

Progress in small pelagic fish research in the 3½ decades since '*Costa Rica*'

Andrew **Bakun**

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The 1983 FAO "Costa Rica" Symposium and its slightly earlier, somewhat smaller precursor, the 1981 IOC-FAO "Lima" Workshop, represented a crucial "jump start" in fishery-environmental science. Just two decades earlier, the largest fished population that has ever existed on earth, the Peruvian anchoveta, had abruptly collapsed in concert with the 1972 El Niño. And during the Costa Rica meeting itself, what may have been the most intense El Nino episode that has ever been recorded was clearly underway and the resulting fates of the very large sardine stocks of the worlds oceans were matters of serious concern. Thereupon, the great Japanese fishery scientist, Professor Kawasaki, pointed out that major sardine stocks located at opposite corners of the Pacific Ocean seemed to be oscillating in a large degree of overall synchrony. These stocks were located so far apart that they were at that time assumed to be entirely separate species that could never conceivably intermingle, forcing the conclusion that their population dynamics had to be somehow controlled by basin-scale climatic processes. Lengthy internationally coordinated research efforts, the IOC-FAO SARP project and its successor, the GLOBEC SPACC Project followed.

As background to initiate the discussions at this current meeting, which has sometimes been dubbed "*Costa Rica II"*, the speaker will present his personal view of prominent findings, inferences, and advances in understanding that have been gleaned over the period since "*Costa Rica I".*

March 6, 10:40 (General Plenary-11693)

Causality linkages in atmosphere, ocean and marine ecosystem over the North Pacific: Modes, processes and prediction

Shoshiro **Minobe**

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Climate variability and change influence marine ecosystem including small pelagic fish, and the major causality is such that the atmosphere forces the ocean, which in turn influences the marine ecosystems. In order to find the presence of such linkages especially between the ocean and marine ecosystem, PDO index (EOF 1st mode of North Pacific SST) is very useful, providing a big picture for coherent marine ecosystem responses to physical forcings. In order to understand better, however, it is necessary to know what physical and biological processes are operating for the relations. In particular, it may be useful to recognize that PDO is a SST pattern forced by Aleutian low variability with several different physical processes shaping that pattern. It is also important to note that physical variability important in marine ecosystems are often not strongly related to PDO or other SST EOF modes. For marine ecosystem predictions that may be operationally possible in near future with one-or-two year lead time, it would be more reliable using predicted SST and subsurface data from operational climate predictions than using PDO or climate mode indices. To confirm feasibility of such predictions, there are several science questions we need to answer. If the answers are positive, marine ecosystem community, PICES, ICES and IMBER may need to work on physical climate communities such as CLIVAR and WCRP.

March 6, 11:15 (Plenary, S1-11901)

Fish scale records from California and Peru reveal new paradigms of variability in climate and small pelagic fish

David B. **Field**[1], Renato Salvatteci[2], Dimitri Gutierrez[3], Kimberly Rose[1], Vicente Ferreira[4], Luc Ortlieb[5], Abdel Sifeddine[5] and Tim Baumgartner[4]

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Testing 20th paradigms of relationships between pelagic fish abundance and climate is done by comparing updated high-resolution records of fish scales from sediments off California and Peru with one another, with instrumental records, and with other paleoclimate records (from the same cores). The 20th century portion of the scale records reflects biomass of sardine, anchovy, and hake and previously identified patterns of climate variability in the latter 20th century. However, the historical variations in fish scales (prior to the 20th century) do not support the modern paradigms. Taken together, sardine and anchovy show no evidence of varying out of phase with one another. In the California Current, sardine actually have a negative relationship with SST (rather than a positive relationship). Furthermore, inferred biomass of sardine, anchovy and hake are all low since the early 20th century off California, in association with a clear ocean warming inferred from fossils of plankton. In contrast, anchovy off Peru has mostly increased during the 20th century, in association with paleo indicators of enhanced productivity. While inferred abundances of anchovy and sardine in the different ecosystems weren't exhibiting synchronous population variations prior to the 20th century, the strong divergence in trends during the 20th century is likely due to different responses of the upwelling systems to global warming trends. Off California, ocean warming is dominating any potential increase in upwelling favorable winds, whereas off Peru an increase in productivity is likely a consequence of greater winds shoaling isopycnals while warming the water column near the surface and offshore.

March 6, 11:50 (Plenary, S2-11755)

From egg production to year class strength: A full life cycle perspective of small pelagic fish recruitment

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Under the general framework of existing recruitment hypotheses, knowledge on the drivers and mechanisms involved in the determination of year class strength is reviewed with emphasis on clupeoid stocks. Whereas recruitment in small pelagic fishes (SPF) is generally considered to be determined primarily by the environment, density-dependent controls that could affect stock productivity have often been identified, especially in the oligotrophic Mediterranean Sea. Levels and variability of egg production differ between stocks/ecosystems and seem to be related to patterns of energy allocation, temperature regimes and planktonic productivity. Although rarely investigated, selective fishing may reduce the reproductive potential of SPF and alter the timing of peak spawning. In attempting to understand the ways by which the ichthyoplankton distribution, abundance and survival are affected by biotic (e.g. environmental optima and tolerances, concentrations of suitable food and potential predators) and physical factors (e.g. temperature, density gradients, currents), it is important to recognize all those milestones in SPF ontogeny that are associated with significant changes in capabilities (e.g. organ development, swimming speed) and behavior (e.g. diel vertical migration, schooling). It is now becoming evident that, in order to disentangle the relative contributions of the different factors involved in the recruitment process, the full life cycle as well as stage-specific features determining survival levels have to be adequately considered. 3-D full-life-cycle bioenergetics IBMs, coupled with hydrodynamic/biogeochemical models, and often including fishing modules, have recently been developed for certain SPF ecosystems, representing new, state-of-the-art tools for simulating population variability in space and time.

March 7

March 7, 9:00 (Plenary, S6-11835)

Small fish, big stake: Vulnerability and adaptation of small-scale small pelagic fisheries to global changes

Ratana **Chuenpagdee** and Manuel Muntoni

Too Big To Ignore Project, Memorial University of Newfoundland, St. John's, NL, Canada. E-mail: ratanac@mun.ca

The ecological and economic importance of small pelagic fisheries is well recognized, but the extent to which the fisheries contribute to livelihoods and food security of fishing communities is less known. Specifically, questions remain about the share of small pelagic fish by small-scale fisheries and the percentage of these small-scale, small pelagic catches destined for human consumption, instead of non-food uses, as with the majority of the catches from industrialized fisheries. For small-scale fishing communities relying on small pelagic fish for food and income, concerns are related not only to competition with large-scale sector but also to stock variability due to global change processes. Again, it is unclear how vulnerable they are to change and what coping mechanisms they employ. It is argued here that knowledge about the interaction between small-scale and large-scale fishing sectors on small pelagic has implications on resource sustainability, and that understanding how small-scale fishing communities cope and adapt to change is imperative to the viability of fishing communities.

March 7, 9:35 (Plenary, S6-11941)

State of small pelagic fish resources and its implications for food security and nutrition

Manuel **Barange**

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The biannual FAO SOFIA Report synthesizes the state of fishery and aquaculture resources globally and regionally, including the contributions from small pelagic fisheries (SPF). In this presentation we will look at the sustainability of SPFs, the patterns of abundance in different oceans, and the implications of such fluctuations and sustainability indices for trade and consumption of fish products. A very significant percentage of SPF are used not for direct human consumption but to produce fishmeal and fish oil, for further use in other animal production systems and, increasingly, in the aquaculture industry. Fishmeal production peaked in 1994 and has followed an oscillating and overall declining trend since then, despite growing demand. Scenarios of future fishmeal production have been developed in the context of food security and the contribution of capture and culture fisheries to achieve global and regional targets. In this presentation we will explore the implications of such projections for the future of SPFs.

March 8

March 8, 9:00 (General Plenary-11856)

Climate impacts on upwelling and the planktonic prey of anchovy and sardine in eastern boundary currents

Ryan R. **Rykaczewski**

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Relationships among various atmospheric, oceanic, and biological processes in eastern boundary upwelling systems continue to attract the attention of oceanographers from all disciplines, particularly in attempt to explain ecosystem changes evident at decadal and multi-decadal frequencies. In these systems, anchovy and sardine populations exhibit prominent variability with distinct periods of growth that are associated with differences in the size structure of the planktonic community and the rate of nutrient supply to the euphotic zone. A number of hypotheses have been offered to describe the impacts of anthropogenic climate change on nutrient supply in upwelling systems, and at least three key components of the upwelling process must be considered: changes in upwelling-favorable winds (including intensification, poleward shifts, and altered seasonality), changes in water-column stratification, and modified characteristics of source waters supplied to the upwelling systems. Testing hypotheses through examination of observational records is hampered by our ability to distinguish the impacts of anthropogenic climate change from those of natural variability, but numerical model projections can offer some insight to changes in the upwelling process over the coming century. I will describe the current understanding of the upwelling response to anthropogenic climate change, compare projected changes in the major subtropical eastern boundary upwelling systems, and postulate about the impacts of such changes on the communities inhabiting the upwelling regions. Improving such understanding is critical for anticipating the future evolution of these systems and their ability to sustain productive ecological communities.

March 8, 9:35 (Plenary, S4-11927)

Methods for assessment of small pelagic fish populations, - do we cope with it?

Reidar **Toresen**

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The assessment of small pelagic fish populations is a story of how to handle uncertainty in the information on the status and dynamics of these populations. Various assessment methods provide more or less the same result when applying the same data sets However, each year, huge effort is put into collecting data for fish stock assessments and still there are large uncertainties in the perception of stock size and population dynamics which appear as inconsistencies between data series. Climate variability and change has led to large variations in terms of stock size and geographical distribution of many population, while abundance estimation methodology and survey design does not always cope with these changes. Another big challenge for the assessment of pelagic fish is the fact that several pelagic fish stocks has a wide geographical distribution which makes it difficult to do abundance estimation with sufficient coverage for consistent abundance estimations. How do we cope with these challenges? The adaptations to the changes both in terms of survey and assessment methodology has been slow. We simply haven't coped sufficiently with changes. To cope we need to focus on the quality of the data sampling, which in practical terms mean to be more adaptive to environmental changes. We also need to include uncertainty of the data sources in the assessments, and make assessments with estimates of uncertainty. In this way both experts of assessments, managers and stakeholders can relate to the quality of our work.

March 9

March 9, 9:00 (Plenary, S3-11823)

How much, where and when? A seabird eye-view on forage fish dynamics and management

Sophie **Bertrand**

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Small pelagic fish in Eastern Boundary Upwelling Ecosystems are sustaining large seabird populations. Seabirds have to some extent the ability to dampen the natural fluctuations of forage fish, skipping reproduction or switching to alternate prey for a while. Yet, adverse climatic conditions combined with heavy fishing pressure may take a heavy toll on their populations. An ecosystem-based management of forage fish fisheries calls for a better knowledge of how much fish should be left at sea for seabirds, taking into account the intrinsic great variability of small pelagic fish populations. The "one third for the bird rule" proposed by Cury et al. (2011) provides a first indicative baseline for global catch quotas. Yet, small pelagic fish fluctuates in terms of abundance but also in terms of accessibility, and that, at a variety of time and space scales. Here we propose to review recent works on seabird behaviour, ecology and demography, to provide a synthetic portray of the role and needs of seabirds foraging on small pelagic fish. In light of this, and examining the outcome of different existing management experiences, we discuss the potential of going beyond the sole "one third for bird rule", by fine-tuning small pelagic fishery management in space and time.

March 9, 9:35 (Plenary, S5-11942)

Will ecosystem approach to fisheries improve our understanding of, and ability to manage, human impacts on variable fish populations?

Kwame A. **Koranteng**

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Management of fish populations is achieved through management of human impacts on the populations. Often, a desire to minimize such impacts, while deriving maximum benefit from the resource, is expressed in high-level policy objectives embedded in statements and documents that are not easy to comprehend or to put into practice. Desired results are only obtainable when an effective, workable interface between policy and actions on the ground, particularly by users of the resource, is developed and implemented, preferably in a participatory way. Efforts made by some countries in Africa to assess and manage fisheries-related impacts on fishery resources and ecosystems, using a participatory planning tool for integrated management of human activities, are described. Examples are given from both small-scale and industrial fisheries. Very interesting results have been obtained which show, among others, that resource users and managers learn from each other on the nature and better use of the resources. It is clear also that success, in terms of actual achievements measured against desired outcomes, is considerably higher when the parties understand each other, having sat to discuss issues as equals and/or respecting each other's views, and coming up with management measures, in a transparent way, that can be efficiently implemented and monitored.

Session 1
Oral Presentations

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

SESSION 1, DAY-1, March 6

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

March 6, 14:10 (S1-11840), Invited

Synchrony in climate and biological response within and among the Benguela and California Current ecosystems

Bryan A. **Black**

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Anchovies and sardines are economically and ecologically important to the structure and functioning of eastern boundary current ecosystems, transferring energy in plankton to upper-trophic fishes, sea birds and mammals. Populations of these small pelagic fish populations often appear to covary not only within, but also among widely separated eastern boundary current ecosystems. As part of the California-Benguela Joint Investigation (CalBenJI), we examine this covariability across the California Current and Benguela Current ecosystems not only in terms of sardine and anchovy populations, but also in the response of upper-trophic indicators, especially seabirds, which are efficient samplers of small pelagics. We amass an array of time series including anchovy and sardine recruitment, spawning stock biomass as well as records of seabird population sizes, diet, reproductive success, phenology, and survivorship within and across the two systems. An index of coastal upwelling was developed, defined as the sum of all positive Ekman transport. Coastal upwelling, pelagic fish populations and seabird indicators show evidence of synchrony across systems. This was most pronounced for variables sensitive to Jan-Apr climate variability, a time of year in which teleconnected climate patterns are most energetic in the California Current. The ultimate drivers of such synchrony remains unclear, though there are relationships with Pacific Decadal Variability, which could indicate quasi-global climate forcing through the simultaneous action of the El Nino Southern Oscillation in both hemispheres.

March 6, 14:40 (S1-11819)

Interdecadal upper ocean hydrology of the Northern Humboldt Current System and its impact on the small pelagic fish distribution

Carmen **Grados**[1], David Correa[1], Gertrudes Luque[1], Jorge Quispe[1], Cecilia Peña[1], Alexis Chaigneau[2] and Vincent Echevin[3], José Salcedo[1], Luis Vásquez[1] and Dimitri Gutiérrez[1]

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3 Laboratoire d'Océanographie et de Climatologie: Expérimentation et Analyse Numérique (LOCEAN), Université P. et M. Curie, CNRS, IRD, MNHN, UPMC, Paris, France
4 Interdecadal long term fluctuations in the hydrology of the North Humboldt Current System and its control over pelagic fish populations is studied.

Sea temperature and salinity high resolution gridded fields developed for the NHCS with all available data, thermocline and water mass distribution, climate indices and anchovy landings and spatial aggregation of this small pelagic fish for the period 1960 to 2014 are analyzed. Low-frequency SST anomalies revealed 3 interdecadal periods since 1960's: a cold phase from 1960 to 1978, a warm phase from 1979 to 1998 and a cold phase from 1999 to 2014, mainly in phase with the Pacific Decadal Oscillation. These low-frequency variations are strongly correlated (r = 0.92) with the low-frequency variability of the 17°C isotherm depth determined from the available in-situ profiles in the near-coastal region (0-100 km; 4°S-18°S) and associated with the seasonal thermocline. Along the Peruvian coast, the seasonal thermocline shows typical fluctuations of ± 5-10 m at interdecadal scales. The interdecadal fluctuations of both the SST (± 0.5°C) and the 17°C isotherm depth (± 10 m) are in agreement with previous regional estimates along Peru and Chile.

During the warm interdecadal periods, anomalously warm waters are found mainly nearshore between 8°S and 17°S whereas weaker offshore (~ 100 km from coast) negative anomalies are encountered between 8°S and 13°S. Expectedly, the opposite pattern is evidenced during cold periods. The spatial structure of the anomalies at interdecadal scales and the possible modulation of fish spatial aggregations is discussed.

March 6, 15:00 (S1-11781)

Environmental impact on fluctuations of juvenile sardine (*Strangomera bentincki*) in the central-southern Chile (32°-47°S)

Karen **Walker** and Antonio Aranis

Fisheries Development Institute (IFOP), Blanco 839, Valparaiso, Chile. E-mail: karen.walker@ifop.cl

The common sardine (*Strangomera bentincki*) is one of the most important resources for fishing in the south-central Chile 32° - 47° S and commercial exploitation is highly dependent from annual recruitment with maximum catches during the first half of each year. Variability in the abundance of the species at different stages of their cycle is associated with changes in the environment and high natural mortality.

The relationship between the change in the multivariate ENSO index (MEI) and the percentage of juveniles (<9.0 cm Total length) sardine in order to observe the influence of environment on recruitment for the south-central area Chile will be analyzed.The data analyzed are sampling information by the Fisheries Research Institute (IFOP) for the period 2002-2016.

Information is a time series, where the month is the unit of time (t) and Mei and percentage juveniles (<9.0 cm total length) as time series (x), the relationship between these two indices is evaluated through cross correlation analysis (CCF).

March 6, 15:20 (S1-11779)

Conceptual model for common sardine (*Strangomera bentincki*) in the south central zone of Chile (32°-47°S)

Antonio **Aranis**, Jaime Letelier and Karen Walker

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In Chile, the largest pelagic fishing activity is concentrated in the center-south (32°- 42°S) area mostly artisanal and sustained for about fifteen years on the stock of sardine, resource forming a multispecies fishery together anchovy and horse mackerel. These species are characteristic of upwelling systems, considered opportunistic strategists, fodder for their contribution to the food chain and small (less than 20 cm Total Length) exhibiting rapid growth but a high rate of natural mortality and being strongly influenced by environmental factors in all stages of their life cycle. In addition, they show a coastal spatial distribution, for the spatial expression of spawning (eggs and larvae) and the distribution of juveniles and adults. Due to the high variability the common sardine, mainly linked fisheries and environmental changes one, it is necessary to know the relationship environment -resource for the development of a sustainable fisheries management in time.

Biological, fisheries and oceanographic information was compiled with the object of developing a conceptual model to facilitate understanding of the interactions between system components, characterizing the habitat and the life cycle of the resource identifying the main bio-oceanographic variables with emphasis on the reproductive process and recruitment.

March 6, 16:00 (S1-11726)

Effects of ENSO phases on Peruvian anchovy spatial aggregation patterns

Giancarlo **Moron**[1,2], Josymar Torrejon-Magallanes[1], Wencheng Lau-Medrano[1], Paola Galloso[1,3], Katia Arones[1] and Dimitri Gutiérrez[1,4]

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The Peruvian anchovy (*Engraulis ringens*) is the most important small pelagic of the Humboldt Current, supporting the largest mono-specific fishery in the world. Previous studies have tried to link spatial indicators with environmental variables, being the most of them limited to a temporal analysis. The aim of this study is to analyse fluctuations on anchovy aggregation patterns and its relationships with set of variables in the period 1992-2016, focusing on the main El Niño/La Niña events. We employed survey acoustic data to model anchovy spatial abundance in a Bayesian framework, using the integrated nested Laplace approximation method with a SPDE approach to model the spatial component. Having obtained spatial distribution, we calculated a set of patchiness indicators which were modelled, using generalized linear models (GLM), by a suite of oceanographic variables, including zooplankton biomass and fish length size. During the most important El Niño/La Niña events, map comparison tests was employed to look for similarities between anchovy spatial distribution and oceanographic features. A detailed discussion is made using the main variables that trigger patchiness and temporal changes in aggregation patterns in a wide temporal window, being able to observe similar patterns during El Niño 1997/1998 and 2014-2015/2016 and the opposite during La Niña 2013. Spatial analysis gives us clues about preferences of anchovy high density patches, finding zooplankton as an important driver of this behaviour. Finally, we include in our discussion other sources of information in order to have a complete view of all processes carrying out during these events.

March 6, 16:20 (S1-11586)

Effects of El Niño 1997-98; 2002-03 and 2015-16 in spatial distribution, concentration of catch and reproductive activity of anchovy in northern Chile

Carola Hernández **Santoro**[1,2] and Jorge Castillo Pizarro[1]

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The captures of anchoveta (Engraulis ringens, Jenkins 1842) represents 90% of total catches of northern Chile. In this paper we analyze the effects of Multivariate Equatorial Index (MEI) as El Niño indicator in reproductive behavior; spatial distribution and concentration of catches of anchovy carried out in the northern of Chile. The spatial catches indexes used are: center of gravity (CG), inertia (I), coverage spatial (CSI), Gini (GI) and spatial concentration (SCI), while the reproductive index used is the Gonadosomatic Index (GSI). Our analisis are focussed in El Niño strong to moderate (1997-98; 2002-03 and 2015-16). The results show that at the beginning of the event El Niño, the catches of anchovy were concentrated towards the shore with the increasing of the following, Gini and Spatial Concentration and indexes Spatial Coberture decrece. While during the event, these indices decline. Also during El Niño the CG it moves south and the catches decreased, mainly due to lowest disponibility of anchovy due the deepening the thermocline and oxycline. Also the specimens lowest to 12.0 cm in length were concentrated and move towards the southern study area, this change of distribution is correlated positively with thermal anomalies; MEI and SCI. Also El Niño delayed the beginning the reproductive activity of anchovy until 2 weeks; and increasing up to 50% the participation the juvenile specimens between 12.0 and 13.5 cm, in the reproductive process, reducing the intensity of the GSI due the increased involvement of juvenile.

March 6, 16:40 (S1-11838)

Modelling the habitat of anchovy (*Engraulis ringens*) between 2007 - 2016 off the coast of the Southeast Pacific

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Anchovy is an economically important resource in Chile, contributing 30% to the national landing. Distribution of this resource extends from the northern limit at 18°25'S to 41°40'S, with three administratively defined fishery units (macro zones) with individual quota regimes and closed seasons. Several hydroacoustic campaigns have been carried out with the main objective of estimating biomass and species distribution, which were developed within the macro zones where each fishery is located. The basis information of these surveys comprises acoustic data of anchovy (adults and juveniles), oceanographic conditions, plankton, and meteorology.

This work considers implementing a species distribution model based on information from the hydroacoustic cruises and spatial indices between 2007 and 2016, for the entire Chilean coast during the austral summer, coinciding with the massive anchovy recruitment period. To that effect, the possible resource–environment associations intend to identify spatio-temporal changes in the distribution patterns of the analyzed historical series, considering the influence of environmental factors and the spatial scale at which they develop.

Keywords: Anchovy (Engraulis ringens), hydroacoustic surveys, species distribution models (SDMs)

March 6, 17:00 (S1-11850)

Displacements of the Peruvian anchoveta stocks in relation to environmental conditions: An analysis using length structure analysis from Vessel Monitoring System information

Josymar Torrejon-Magallanes and Wencheng **Lau-Medrano**

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Peruvian anchoveta is, ecological and commercially, the most important species of the Humboldt Current System. Typically, there are two main distinct stocks in the area: Northern - Central (04°00'S – 15°59'S) and Southern (16°00'S – 18°21'S). There is little information about displacement: One work based on tagging (in 1970) which described large displacements associated to reproductive processes, while another studies suggest this event could be related to environmental factors. The aim of this work is to analyze possible displacements (from south to north and vice versa) of the stocks and their relation with environmental variables as water masses dynamics, upwelling, winds and Kelvin, and other information in order describe how this process is carrying out. In a weekly time step, we use length structures of catches by latitude during the fishing seasons of 2010 – 2016 around the conventional limit of stocks (16°S). As a result, we found that some environmental variables trigger displacement between stocks and observed similar patterns during El Niño 2014-2015 and the opposite during La Niña 2013.

March 6, 17:20 (S1-11900)

Multifarious anchovy and sardine regimes in the Humboldt Current System during the last 150 years

Renato Salvatteci[1], David Field[2], Dimitri **Gutierrez**[3], Tim Baumgartner[4], Vicente Ferreira[4], Luc Ortlieb[5], Abdel Sifeddine[5] and Arnaud Bertrand[6]

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The Humboldt Current System (HCS) has the highest production of forage fish in the world, though it is highly variable and the primary component, anchovy, are predicted to decrease with continued warming. Paradigms based on late 20th century observations suggest that large scale climate controls decadal-scale fluctuations of anchovy and sardine across different boundary currents of the Pacific. We test current paradigms with fish scales from multiple laminated sediments along the HCS to compare anchovy and sardine fluctuations since 1860 AD with Tropical Pacific and local indices of ocean-climate variability. Our records reveal: 1) two main anchovy (~1910-mid 1970s, and from the late 1990s to the date) and two sardine phases (~1880–1910, and mid 1970s–late 1990s) that display irregular periodicity; 2) multiple modes of variability of anchovy and sardine fluctuations rather than strict alternations; 3) regionally coherent anchovy and sardine fluctuations with habitat-related differences; and 4) anchovy and sardine fluctuations are driven by changes in upwelling intensity, rather than the PDO, likely via the modification of the 3-D habitat. Additionally, a long-term increase in coastal upwelling translates via a bottom-up mechanism to top predators, suggesting that regional manifestations of climate warming have been, until now, favourable for fishery productivity in the HCS.

March 6, 17:40 (S1-11884)

Ontogenic variability of the ecological niche of Peruvian anchoveta (*Engraulis ringens*): Impacts on its present and future distribution

Criscely **Luján-Paredes** and Ricardo Oliveros-Ramos

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Spatial distributions models are numerical tools that allow to know the spatial distribution and the ecological niches of species relating spatial distribution data with environmental information. There are several studies which have used this kind of models but worked with an integrated niche without differentiation between stages of development of the Peruvian anchovy. The aim of the work was to analyze if there are differences in the ecological niches of anchovy given the developmental stages. We work with three stages of development of anchovy: pre-recruits (from 0 cm to 8 cm), recruits (from 8,1 cm to 11,5 cm) and adults (from 11,6 cm to 20 cm); environmental data of remote sensing to four variables (sea surface temperature – SST, sea surface salinity – SSS, surface chlorophyll-a – CHL, and oxycline's depth - OXI); and an statistical niche modelling which used generalized additive models (gams). The results showed a differentiated ecological niche for each development stages being the SST and OXI the factors that limited the pre-recruits niche; while the CHL and OXI were the limiting factors of recruits niche and adults niches. On the other hand we found differences in the anchovy distribution by each stage, being pre-recruits those who had a more coastal distribution while recruits and adults showed an oceanic distribution. We recommend to do separate studies for stages, which allows better understand of ecological relationship found in the results of the ecological niche, also do simulations with niche models that include more environmental variables, which can improve anchovy spatial distribution maps.

SESSION 1, DAY-2, March 7

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

March 7, 10:40 (S1-11866)

Climate, anchovy and sardine

David M. **Checkley**, Jr.[1], Rebecca G. Asch[2] and Ryan R. Rykaczewski[3]

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Anchovy and sardine populated productive ocean regions over hundreds of thousands of years under a naturally varying climate, and are now subject to climate change of equal or greater magnitude occurring over decades to centuries. We hypothesize that anchovy and sardine populations are limited in size by the supply of nitrogen from outside their habitats originating from upwelling, mixing, and rivers. Projections of the responses of anchovy and sardine to climate change rely on a range of model types and consideration of the effects of climate on lower trophic levels, the effects of fishing on higher trophic levels, and the traits of these two types of fish. Distribution, phenology, nutrient supply, plankton composition and production, habitat compression, fishing, and acclimation and adaptation may be affected by ocean warming, acidification, deoxygenation, and altered hydrology. Observations of populations and evaluation of model skill are essential to resolve the effects of climate change on these fish.

March 7, 11:00 (S1-11853)

Recent trends in the Peruvian Coastal Upwelling Ecosystem and implications for the anchovy habitat

Dimitri **Gutiérrez**[1,2], Carlos Romero[1], Dante Espinoza[1], Criscely Luján[2], Luis Vásquez[1], Michelle Graco[1], Carlos Quispe[1], David Correa[3], Jorge Tam[1], Vincent Echevin[3] and Ricardo Oliveros[2]

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The Peruvian Coastal Upwelling Ecosystem (PCUE) supports the largest fishing production among analog systems in the globe, mostly based on one species, the Peruvian anchovy *Engraulis ringens*. The low latitude position in the Pacific makes the PCUE dynamics, productivity and fish stocks especially sensitive to climate variability and climate change. Recent studies have suggested a reduction in the anchovies' nursery area, in response to increased stratification and lower productivity, under climate change scenarios. Here we analyze recent records of oceanographic variables and its implications for the anchovy habitat distribution in the main region for its largest stock (04 – 16°S). Coastal surface waters have exhibited a significant cooling trend since the 1970's to the early 2000's, which has been accompanied by a positive trend in the surface chlorophyll-a concentration. For the last decade, it is evidenced an increasing propagation of intraseasonal Kelvin waves, particularly during autumn periods, followed by warming and a shoreward retreat of the thermal front. Data from other oceanographic variables, as surface chlorophyll-a concentration and oxycline depth, also indicate changes in their spatial and seasonal behavior. Application of a niche bioclimatic model for these environmental changes suggest a negative impact for the potential distribution of anchovy, especially for less developed stages as pre-recruits and recruits, whose spatial distributions and ecological niches are reduced compared with that obtained by more developed stages as adults.

March 7, 11:20 (S1-11943)

Evidences anthropogenic and environmentally driven regime shifts in Peruvian pelagic fisheries

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Until the late 1950s the anchoveta was virtually unexploited and in high abundance, further favored by the severe successive declines in 1957-58 and 1965 of some of its main predators, the guano seabirds, which since then have given little or no signs of recovery. The high abundance period of anchoveta observed during the 1950s and 1960s didn't last much longer. Overfishing combined with the effects of the strong El Niño 1972-73 caused its severe decline and its entering into a period of particularly low abundance that lasted until the mid 1980s, with a clearer full from 2000 onwards. The drop in the abundance of anchoveta in the early 1970s caused a shift to low abundance levels of Eastern Pacific bonito, from which bonito hasn't recover even if the anchoveta has recovered to its pre-1970s high abundance levels. The two periods of anchoveta high abundance are associated with colder water environmental conditions off Peru, as characterized by the prevalence of negative anomalies of sea surface salinity, sea surface temperature and shallower oxygen minimum zone. These two periods were also subject to slightly different fisheries management approaches, a more relaxed in the 1960s and a more conservative, better informed adaptive approach since the 1990s. Other important shifts in abundance of pelagic species observed during the 1970s and 1980s are the temporal (decadal) increase in abundance of sardine (Sardinops sagax), jack mackerel (*Trachurus murphyi*) and Pacific mackerel (*Scomber japonicus*) associated with warmer environmental conditions observed from the mid 1970s throughout the mid 1990s. Jumbo flying squid (*Dosidicus gigas*) has also increased since the early 1990s and now sustains and important local fishery. The ample low frequency variability in the abundance of key species in the Peruvian pelagic marine ecosystem poses particular challenges throughout the whole fisheries management decision making process in Peru, as it calls for improved and continuously updated understanding of the prevailing environmental conditions and their interactions with the exploited fish stocks.

March 7, 11:40 (S1-11945)

Are there early signals of a new warmer "sardine cycle" in the Peruvian upwelling system? Some implications for fisheries management

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The effects of long term changes variability is one of the challenges that fisheries administrations must address; and development of early signals is one of the most urgent tasks of fisheries science. This is particularly important when biotic and abiotic signals show concurrent changes in their trends. Some interesting changes has been observed in different climate variables in Peru Current System, which may suggest a departure from the colder "La Vieja" or "anchoveta favorable" conditions that have prevailed since the late 1990s. The period 2012-2016 has been warmer than average and different biological signals of change has been observed in different components of the ecosystem through fishery indicators. Most noticeable signal was the sparse but increasing presence of sardine (*Sardinops sagax*) and Pacific mackerel (*Scomber japonicus*) in the pelagic commercial catches, the increased abundance and availability of Peruvian hake (*Merluccius gayi*), gurnards (Triglidae) and other demersal species. While sardine and Pacific mackerel are indicators of warm waters masses, Peruvian hake and gurnards are indicators of better bottom oxygen conditions. Both, warmer than average sea surface temperature and higher than average bottom oxygen contents are characteristics of what has been called a "warm regime" or "El Viejo" regime (Chavez et al 2008). In 2009-2010 an international workshop about Peruvian anchoveta (IMARPE, 2010) concludes that a possible regime shift or a change in the trend (break point) of the low frequency variability of some environmental signals could occur between 2015 – 2020. Are the observed changes in agreement with that forecast? Some insights on the differences between the state of Peruvian anchoveta population in the 1970s and at present are discussed.

March 7, 12:00 (S1-10863)

Diet diversity of jack and chub mackerels and ecosystem changes in the northern Humboldt Current system: A long-term study

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Jack mackerel *Trachurus murphyi* (JM) and chub mackerel *Scomber japonicus* (CM) are medium size pelagic fish predators and highly exploited resources. We investigated the spatiotemporal patterns of JM and CM diet composition using a large dataset of stomach samples collected from 1973 to 2013 along the Peruvian coast. In total 47,535 stomachs (18,377 CM and 29,158 JM) were analysed, of which 23,570 (12,476 CM and 11,094 JM) were non-empty. Results show that both species are opportunistic and present a trophic overlap. However, despite their smaller maximal size, CM consumed more fish than JM. Both diets presented high spatiotemporal variability. Spatially, the shelf break appears as a strong biogeographical barrier affecting prey species distribution and thus CM and JM diet. Opportunistic foragers are often considered, as actual indicators of ecosystem changes; we show here that diet composition of CM and JM reveal ecosystem changes but is not always a good indicator of changes in prey biomass, as prey accessibility and energy content can also play an important role. In addition, we found that El Niño events have a surprisingly weak effect on stomach fullness and diet. Finally, our results show that the classic paradigm of positive correlation between diversity and temperature is unlikely to occur in the Northern Humboldt Current system where productivity seems to be the main driver. We show how energy content of forage species and the strength of the oxygen minimum zone most likely play an important role prey diversity and accessibility, and thus in fish foraging behaviour.

March 7, 12:20 (S1-11800)

Impact of ocean stratification on small-scale physical oases for pelagic life

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Physical forcing of the surface ocean includes a variety of energetic processes, ranging from internal wave (IW) to submesoscale and mesoscale. Recent works based on acoustic data showed that, off Peru, the vertical displacements of the oxycline depth provide a robust proxy of isopycnals displacements over a wide range of horizontal scales. These studies revealed the importance of ephemeral hotspots (oases), which concentrate organisms ranging from zooplankton to seabirds, enhancing trophic interactions. Here, we address the question of the potential impact of climate variability on these fine-scale oases for life. Indeed, temperature and salinity changes induced by climate change are expected to lead to an ocean near-surface stratification increase that could have a negative impact on the intensity of physical small-scale structures and, consequently, on patterns distribution of marine life. For that we use 35 000 physical structures from acoustic data collected during twelve scientific surveys conducted between 2002 and 2011 off Peru. We estimate the strength of these structures, its power of aggregation on zooplankton and small pelagic fish and also ocean stratification conditions. Results show that higher the ocean stratification, less the strength and the power of aggregation of the fine scale physical structures. Climate variability, and potentially climate change, could thus lead to a reduction of the size and density of organisms patches with a potential impact on consequent trophic interactions.

March 7, 14:00 (S1-11739)

Global diversity and abundance of small pelagic fishes in the end of the 21st century

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Small pelagic fishes (SPF) support important fisheries all over the world, but their population dynamics is highly dependent on ocean/climate variability, which raises concern about their viability given ongoing climate change. Here we present an ensemble forecast of global changes in SPF (anchovies, herrings and sardines) diversity, abundance and geographic range size, under strong (Representative Concentration Pathway, RCP2.6) and business-as-usual (RCP8.5) scenarios. We show that between 45% and 46% of the current habitat of SPF species could lose its suitability, by the end of the century. In turn, abundance was projected to decline between 32% and 44%, under the different mitigation scenarios. Between 77-93% of the species were projected to shrink their geographic range and shift their mean latitudes poleward. Anchovies are the biggest losers in a future climate change scenario, with 51% of the species projected to fully lose their habitat suitability. Our results highlight the need for precautionary management that account for uncertainties and flexible measures easily adaptable to these changes.

March 7, 14:20 (S1-11665)

Collapse and recovery of forage fish populations before commercial fishing

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We use a new, well calibrated 500-year paleorecord from southern California to determine collapse frequency, cross-correlation, persistence and return times of exploited forage fish populations. The paleorecord shows that "collapse" (defined as < 10% of the mean peak biomass) is a normal state repeatedly experienced by anchovy, hake and sardine which were collapsed 29 − 40% of the time, prior to commercial fishing exploitation. Mean (±SD) persistence of 1/3 mean peak biomass from the paleorecord was 19±18, 15 ± 17, and 12 ± 7 years for anchovy, hake, and sardine. Mean return times to the same biomass was 8 years for anchovy, but 22 years for sardine and hake. Further, we find that the current paradigm of sardine-anchovy alternations an artefact of short time series, and that sardine and anchovy are positively correlated on the 500-year time scale, consistent with coherent declines of both species off California. Persistence and return times, combined with positive sardine-anchovy correlation indicates that on average 1−2 decades of fishable biomass will be followed by 1−2 decades of low forage. Forage populations are resilient on the 500-year time scale, but their collapse and recovery cycle is fitted to pulsed exploitation strategies.

March 7, 14:40 (S1-11711)

Tracking the spatial dynamic of sardine abundance changes in the California Current large marine ecosystem: An approach to elucidate local and broad scale environmental drivers and their interactions

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Scientific debate regarding environmental drivers and future trends of sardine populations is hampered by a lack of understanding of the spatial dynamic within changing large marine ecosystems (LME). An oversimplified assumption of uniform biomass expansion-contraction shifts is the prevailing paradigm. This as consequence of assuming that environmental drivers affect sardine biomass levels in the same way across LME within the same time-scale. We provide evidence against this paradigm by reviewing and integrating the spatial patterns of sardine in the California Current (CC), particularly those related to specific temporal scales of SST. We focus on seasonal migrations, inter-annual distribution changes during ENSO events, and latitudinal shifts in the center of distribution and bulk of abundance on multi-decadal scale. The ultimate goal is to understand how spatial processes at different scales are inter-related to produce the observed macro-scale changes in abundance. To address this issue, we reconstruct the seasonal and inter-annual spatial dynamic of sardine population during the last warming period, when sardine biomass recovered in the CC, based on spatially explicit monthly CPUE records of tuna bait-boats along the southern part of the CC during an 18-years period (1980-1997). Our results suggest that the reappearance of sardine in the north part of the CC ecosystem is a result of population movement that originated from its core distribution in the south. Moreover, rather than a uniform pole-ward shift, we provide a nuanced description of spatial variability in order to properly elucidate and test drivers and interactions between all scales of climate-ocean variability.

March 7, 15:00 (S1-11733)

Use of environmental indices to predict the recruitment of Pacific sardine

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That the environment is highly influent on the productivity of small pelagic fishes is a widely accepted assertion. However, environmental indices have only been used to explain and forecast recruitment for a few species. Recruitments to the northern stock of Pacific sardine have been estimated from a stock synthesis model, and covariation of the resulting recruitment time-series has been evaluated for numerous environmental indices. For example, a running 3-year mean of sea-surface temperature (SST), measured at the pier of Scripps Institution of Oceanography, was used for more than 10 years to model the productivity of the northern stock of Pacific sardine and to set harvest rates. Because that model did not sufficiently track a decline in the stock between 2006 and 2012, it was replaced by a new model including an SST index from spring surveys of the usual offshore spawning area. Two years later, however, the recruitment time series used to generate the recruitment model was revised using a new stock synthesis model fit with landings apportioned to southern and northern sardine stocks. Here, we evaluate the role of the environment on the productivity of the northern stock of Pacific sardine using the refined assessment time-series of biomass and recruitment.

March 7, 15:20 (S1-11789)

Climate variability and recruitment dynamics of sardine in the California Current: A mechanistic analysis of an end-to-end model

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A fully coupled end-to-end model was used to explore the response of sardine population to climate-ocean variability in the California Current System (CCS). We focus on understanding the effects of major regime shifts and El Niño/La Niña events on sardine distribution, growth, mortality, and recruitment during the 1965-2006 period. An individual-based model (IBM) represented the full life cycle of sardine (eggs, larvae, juveniles and adults) by simulating the key biological processes: development, growth, mortality, movement and reproduction. A coupled hydro-biogeochemical model provided the 3-dimensional physical (water velocities, temperature) and prey fields (zooplankton) as inputs for the IBM model. During the 1983, 1992, and 1997-98 El Niño years, spawning grounds were expanded to the north as a result of geographic shift of optimal temperature for reproduction and the somatic condition of mature individuals. Modelled sardine growth showed notable spatial variations following the spatial and temporal patterns of temperature and plankton concentrations within the IBM domain. Simulated recruitment demonstrated that reproductive output of spawners and larval survival must act synergistically to explain observed recruitment variability. We finally discuss how our results can be used to identify interannual changes in the geographic range of sardine population, given that the CalCOFI sampling area does not sample the entire area of sardine potential habitats. Our analysis provide an important step to mechanistically link environmental drivers to fluctuations in sardine recruitment in the CCS.

March 7, 16:00 (S1-11907)

Seasonal climate predictions to improve forage fish management

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Forage fish populations are strongly influenced by climate variability. The inability of fisheries managers to anticipate such environment-driven fluctuations in forage fish productivity can lead to overfishing and stock collapses. We show that recent advances in dynamical global climate prediction systems such as the state of the art NOAA Geophysical Fluid Dynamics Laboratory (GFDL) 2.5-FLOR model, allow for skillful sea surface temperature (SST) anomaly predictions at a seasonal scale over many shelf ecosystems. Such seasonal forecasts were coupled to a population dynamics model of Pacific sardine in a management strategy evaluation framework to evaluate harvest strategies more robust to climate variability. The harvest guideline that incorporated stock biomass forecasts informed by skillful SST predictions led to increases in stock biomass and yield, and reductions in the probability of yield and biomass falling below socioeconomic or ecologically acceptable levels. However, to mitigate the risk of collapse in the event of an erroneous forecast, it was important to combine such forecast-informed harvest controls with additional harvest restrictions at low biomass. This analysis highlights the utility of skillful seasonal climate predictions to enhance forecast capacity for marine ecosystem and build management systems more resilient to climate variability and change.

March 7, 16:20 (S1-11881)

Non-fishery collapse of northern anchovy in California: Climatic and biotic hypotheses

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Biomass estimates for the central subpopulation of northern anchovy (*Engraulis mordax*) in the California Current indicate a collapse in the population which started after a major recruitment event in 2005, and has continued to the present. Biomass estimates were based on egg and larval sample densities from CalCOFI surveys for January and April; these were geo-spatially weighted, summed to obtain total abundance, developed into a combined index of productivity, and then calibrated to early 1980s absolute biomass estimates based on the Daily Egg Production Method (DEPM). Larvae to egg ratios were low from ~2000 through 2012, but have recently recovered to levels seen earlier in the CalCOFI time series. In this study, we test the hypothesis that low-frequency variability in the larvae to egg ratio is related to winds and other coastal and offshore upwelling characteristics, as well as interactions with coexisting small pelagics, specifically sardine. Since about 1990 in southern California there has been a pattern of spatial exclusion so that spawning sardines and anchovies rarely inhabit the same water. The range of anchovies is constricted and we hypothesize that the high densities are conducive to intense filter feeding cannibalism. This study provides a framework for understanding why sardine and anchovy population fluctuations may be in- or out-of-phase with one another.

March 7, 16:40 (S1-11889)

Primary productivity contribution to climate-catch models of Pacific sardine

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Small pelagics present a relatively quick response to physical changes where they inhabit. Some small-pelagic species have also shown responses to slow climatic changes (e.g. Pacific Sardine). A range of conditions in temperature, winds, stratification and upwelling intensity, can be modulated remotely by climate patterns, affecting presence/absence of small-pelagics at different life-cycle stages. The precise mechanisms controlling survival/mortality rates have not been described entirely, representing a handicap to develop appropriate modelling approaches. Climate-catch models hold the advantage of being simple and retain a high potential utility for management decisions. Climate-catch models might be enhanced including key biological process connecting the physical environment with higher trophic levels in marine food webs. This work is aimed to evaluate the contribution of PP in climate-catch models of Pacific sardines at the eastern margin of the North Pacific basin. Historical time series for fishery catches reported at three fishing ports (between Mexico and Canada), Primary Productivity (PP), Upwelling and Eddy Kinetic Energy data, were introduced to climate-catch models. Systematic assessment of PP-related processes was conducted in terms of statistical criteria (*e.g.* R^2, information lose). Results might be applied to complex modelling strategies (*e.g.* End to End models) and decision making processes in particular socio-ecological systems.

March 7, 17:00 (S1-11869)

Temporal changes in size-at-age: Impact and implications on reproductive biology and egg density of Pacific herring in British Columbia

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Age-specific declines in length and weight of Pacific herring occurred in all areas of British Columbia (BC) approximately from 1985-2010, followed by a recent reversal in that trend. Concurrent with declining age-specific size, egg density on spawning grounds declined but this trend also has reversed. The number of layers of egg deposited on vegetation, estimated from diver surveys, declined from about 2-3 to 0.5-1 layers. In general, as egg density (approximated by the number of egg layers) declined, no corresponding reductions occurred in other dimensions of herring spawning beds: mean length, total length or total spawning bed area (m^2). In many locations spawning bed widths increased as number of layers of spawn decreased. Correlation analyses indicate that the coherence of these two independently measured trends (declining size-at-age and declining egg density) is highly significant ($p<<0.01$) in all regions of the BC coast. The biological basis for these temporal changes can be explained by size-dependent relative fecundity (eggs/gm) that is lower in smaller herring and (2) variation in density of spawning fish that is inversely related to fish size. In short, smaller fish sometimes use more spawning area (m^2) to deposit lower egg densities. Quantitative estimates of herring spawn deposition are integral for herring spawning stock biomass assessments in BC and elsewhere so it is important to understand the factors that affect egg density. Our analyses indicate that climate-induced changes in herring growth (size-at-age), beginning in the first year of life, can subsequently impact parameters of reproduction and spawning behaviour.

March 7, 17:20 (S1-11743)

Exceptional fish beaching off Arthungal, Alappuzha, along the southwest coast of India: Search for the possible cause

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The South-East Arabian Sea is one of the well-known upwelling systems in the north Indian Ocean, and is the site of the splendid Indian oil sardine *(Sardinella longiceps)* fishery. In the recent years, there has been a serious concern that the oil sardine fishery stock is declining along the southwest coast of India. Fish landing data show that Indian oil sardine fishery has dwindled spatially and temporally over the last few decades, and the possible attributes could be many including the intensification of coastal hypoxia, ocean warming and climate change. In this paper, we present a very interesting and unusual beaching of live oil sardine occurred off Arthungal, Alappuzha, along the Southwest coast of India in January 2013 (Northeast Monsoon). Based on the satellite and modelled data, here we search the causes of the unusual event that has received considerable attention from electronic and print media. We analyzed the time series of several relevant oceanographic parameters (temperature, salinity, oxygen, wind, currents, chlorophyll) representing the region where the beaching of oil sardine incident has occurred, but failed to figure out any striking oceanographic features including coastal hypoxia responsible for the incident. Therefore, the relevant factor behind the incident might be the physical disturbance/stimulus caused by severe coastal fishing activity, that might eventually directed/induced a large school of oil sardine present in the region to ashore along the beaches in the region. It is pertinent to note that the current incident was quite unusual as it was neither reported before nor after.

Key words: Arabian Sea, fish beaching, sardine, Northeast Monsoon, upwelling, hypoxia, fishing

March 7, 17:40 (S1-11725)

Impact of climate change on the population of SPF resources of the Gambia

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The artisanal fisheries sub-sector plays a very important role in providing the vital animal protein supplement to the Gambian populace. Also it acts as a major source of raw fish material for the fish processing establishments in the country. Despite their relative low commercial value, the small pelagic fish resources dominate the total annual catches of the capture fisheries. The marine and coastal fisheries provide the bulk of fish production. Decrease in both fish production and distribution in these areas as a result of various climate change scenarios and fishing pressure will severely impact the wellbeing of the population of (SPF).

The impacts of climate change could result in increased salinization in the estuarine zones which leads to the desiccation of mangroves and other wetland ecosystems that are important critical breeding and nursery habitats for commercially important fish species. it also leads intrusion of salt water into the freshwater habitats *(The River Gambia)* which might deleteriously affect the freshwater fish species.

At present, the assessment of small pelagic resources are made at sub-regional level through the FAO Working Group on the assessment of the small pelagic fish of Northwest Africa. This excellent cooperation between scientists of the sub-region is the first stage for a concerted management of these resources. Management measures are however adopted at the national level and one country's measures do not always correspond to management schemes applied in the neighboring countries.

SESSION 1, DAY-3, March 8

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

March 8, 10:40 (S1-11787)

Revisiting the regime problem hypothesis: 25 years later

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The Regime Problem hypothesis published in 1989 suggests that there is alternation in the abundance of sardines and anchovies in the major fishing regions of the World, and that periods of high and low abundance are synchronous between systems (Japan, California, and Humboldt, and in opposite phase in Benguela). Updated time series (to 2014) of catches from these four systems reveal that in California the sardine abundance does not fluctuate synchronously, and in Benguela the alternation pattern is no longer evident. Further, back in the 1990s many of the small pelagic fisheries were not included in the analyses because the catch time series were too short. Here we applied principal component analysis (PCA) for clupeid (11) and engraulid species (7) of different fishing areas around the globe. For clupeids, the two main components accounted for 53% and 18% of the total variance. The first component is represented by 6 species, distributed in the northeast and central eastern Atlantic, Black Sea and Mediterranean Sea (*Sardinella aurita* and *Sardina pilchardus*), the Indo-Pacific (*Dussumieria acuta*, *Sardinella gibbossa* and *Sardinella lemuru*) and California (*Sardinops caeruleus*). Most of these species showed a tendency to increase their abundance during the period. The second PC is entirely related to the Japan and Humboldt Currents, the two only systems still responding as predicted by the Regime hypothesis. Further analyses will follow to understand to what extent the regime hypothesis should be generalized.

March 8, 11:00 (S1-11763)

Variations in the catches of small pelagic fishes from China seas and their responses to climatic regime shifts

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Small pelagic fishes such as sardine and anchovy play an important role in marine ecosystem and affected largely by environmental changes as the character of r-strategists and their low trophic levels. Small pelagic fishes are crucial targets of Chinese fishery, contributed up to 21.6% of the total catch in 2014, and show increasing trend since 1950s. However, there is little information on small pelagic species in Chinese waters. Here, catch trends and impacts of regime shifts for five small pelagic fishes, chub mackerel (*Scomber japonicus*), Pacific herring (*Clupea pallasi*), Japanese anchovy (*Engraulis japonicus*), Japanese sardine (*Sardinops melanostictus*) and horse mackerel (*Trachurus japonicus*), are analyzed using Chinese fishery statistics, FAO data and climatic indices (Pacific Decadal Oscillation, Southern Oscillation Index, Arctic Oscillation Index, North Pacific Index and Asian Monsoon Index). It aims to explore the variabilities in catches of small pelagic fishes in China Seas and their responses to climatic regime shifts. Results show that evident inter-decadal variabilities occurred in all of the five species with different responding patterns between warm- and cold- water species. Catch of cold-water herring decreased during 1990s and increased in the 2000s with step changes around in 1983/84 and 2000/01, while the catches of others increased in 1990s and decreased in the late 2000s with step changes in 1976/77, 1996/97 and 2006/07. It suggests that decadal variations in small pelagic fishes respond well to the regime shifts occurred in 1976/77 and 1996/97, but the impact of the late 1990s regime shift was not evident for these five species.

March 8, 11:20 (S1-11925)

Catch dynamics of small pelagic fishes in Bali Strait and South Java Sea in relation to the climatic regime shift: Case study on *Sardinella lemuru*

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Indonesia is one of the big producers of big pelagic fishes (BPF) (e.g. tuna, skipjack, etc.) in the world. The existence of BPF is determined by the presence of small pelagic fishes (SPF) in its food chain. The presence of SPF is very important for indicator of bigger fish abundances. Nevertheless, the present of SPF fluctuates due to various reasons, such as overfishing and climatic variability on decadal to multi-decadal scales. In 2006 *Sardinella lemuru* of Bali Strait reached the top of production. However, it was disappear in 2010/2011 leading to collapse for several years. It was predicted that *S. lemuru* migrates both horizontally and vertically due to oceanographic variation. Therefore, this study aims to determine the dynamics of *S. lemuru* in relation to regime shift in last two decades. Results showed that regime shift occurred in 2010, as indicated by the change in Sea Surface Temperature anomalies trend by warm to the cold phase, followed by the disappearance of *S. lemuru* in Bali Strait as well as the presence of it in Sendang Biru waters, or vice versa. In addition, the disappearance of *S. lemuru* may also cause vertical migration of it. For example, during La Niña (2010/2011) event, thermocline was deeper (73m depth) than normal year (61.16m depth). It provides good information for BPF availability due to key species, oceanography, and climatic approach. Since ocean is connected each other, it is suggested that SPF in East Java has to manage jointly with other area for better future management.

March 8, 11:40 (S1-11724)

The influence of ocean dynamics and climate changes on the Lemuru (*Bali Sardinella*) abundance in the Bali Strait, Indonesia

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Bali Strait is a semi-enclosed waters, which located between east Java and Bali Island. A small part of the Indonesian ThroughFlow (ITF) from Makassar Straits and Java Sea influence on the Bali Straits through the narrow northern part of Bali Straits, while in the southern part open to the Indian Ocean. Upwelling process in the southern part occurs normally in June-July-August during southeast monsoon. The watermass upwelled and bring higher concentration of nutrient then during the northwest monsoon (December-January-February). The maximum chlorophyll-a concentration (about 3 mg/m^3) is found at depth of 10 meters during the east monsoon and becoming deeper (up to 20 meters) in second transition monsoon (September) with a concentration of 1.5 to 2 mg/m^3. The abundance of chlorophyll-a during the east monsoon is one of the indicators that correlated with the abundance of Lemuru fish (*Bali Sardinella*) where the maximum catch occurs during the second transition monsoon (September-October-November). The El Nino Southern Oscillation (ENSO) in the Pasific Ocean and Indian Ocean Dipole (IOD) influence on the ocean dynamic of Bali Straits. During El Nino and positive IOD event, Lemuru fish caught twice more than normal conditions. On the contrary, during La Nina and negative IOD temperature of seawater is higher and deep and the upwelling did not occur. The abundance and caught of Lemuru in the Bali Strait became lower.

March 8, 12:00 (S1-11950) CANCELLED

Environmental drivers for pelagic and non-pelagic fish in nearshore habitats of the southeastern Brazilian coast

Marcelo Paes **Gomes**, Leonie Robinson and Matthew Spencer

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Nearshore habitats are important for reproduction, feeding and growth of many fish species and are usually subject to seasonal influxes of adults from other habitats. Understanding which drivers make these habitats suitable for fish species and, in particular, why this might vary seasonally is relevant to resource management. On the southeastern Brazilian coast, detached macroalgae are carried by surface currents and swell and deposited along beaches in the winter (Dry period), but are largely absent in the summer, nutrient-enriched Rain period. This project aimed to determine how period influence fish size and condition in nearshore habitats. Four habitats were surveyed on the southern Espírito Santo coast (Beach, Estuary, Initial Shelf and Shelf). Fish sizes of 15 species were compared among Dry and Rain periods through linear regression models. Three-way ANOVA contrasts were used to compare fish sizes between periods. Sizes were significantly lower in the Dry period for pelagic (*Chirocentrodon bleekerianus*, *Odontognathus mucronatus* and *Pellona harroweri*) and non-pelagic species, even in shelf habitat. Higher slopes were obtained from some fish species in the Dry season, showing that larger fish were heavier for a given length for both pelagic and non-pelagic species. Previous data demonstrated stable isotopic signatures of carbon being shared between detached macroalgae, crustacean and non-pelagic fish in Initial Shelf, which might be considered for a broader extension off from the shore. The data suggest that the Dry period has stronger influence over pelagic and non-pelagic fish in this region, despite of the distance from shore and estuarine discharge.

March 8, 14:00 (S1-11896)

Energy transfer efficiency from zooplankton to forage fish over a eutrophic to oligotrophic gradient in global pelagic food-webs

Brian P.V. **Hunt**[1,2], Francois Carlotti[3], Lian E. Kwong[4], Evgeny A. Pakhomov[1,4] and Iain M. Suthers[5]

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The conversion of energy from zooplankton to forage fish is critical to overall energy transfer from primary producers to upper trophic levels in pelagic food-webs. Two factors central to the amount of energy channeled through this pathway are total primary productivity and the efficiency of transfer of that productivity. Food chain length is an important determinant of the latter, with short food chains expected to be more efficient in energy transfer than long food chains due to lower metabolic losses. Since feeding relationships in pelagic food-webs are strongly size-structured, the size of the dominant producers at the food-web base represents a major potential driver of energy transfer efficiency. Globally, the primary producers that dominate pelagic food-webs vary in size by up to three orders of magnitude, from small picophytoplankton (<2µm) in oligotrophic (nutrient poor) systems to large microphytoplankton (>20µm) in eutrophic (nutrient rich) systems. Here we explicitly examine size-structured trophic dynamics between zooplankton and forage fish across a gradient of eutrophic (British Columbia, South Atlantic) to oligotrophic pelagic food-webs (Mediterranean, South Pacific). Using a coupled biomass spectra-stable isotope approach we estimate food chain length, predator:prey mass ratios and transfer efficiencies between zooplankton and forage fish in each system. We report a range in transfer efficiencies from ~10% in the South Atlantic to <3% in the South Pacific. We discuss the potential drivers underlying these differences, the importance of isotope trophic enrichment factors to estimates, and the application of this approach to understanding likely food-web responses to climate change.

March 8, 14:20 (S1-11401)

Small pelagic fish in the Mediterranean Sea: Alarming body condition and size decline during the last decades

Pablo **Brosset**[1], Jean-Marc Fromentin[2] and Claire Saraux[2]

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Small pelagic fish are among the most ecologically and economically important fish species and are characterized by large scale fluctuations all over the world. In the Mediterranean Sea, a constant low biomass situation has been observed in some areas during the last decade, without trend inversion. Here we studied the anchovy and sardine body condition variability, a key index of population health and its response to climatic variability in nine Mediterranean areas between 1975 and 2015.

Results showed that anchovy and sardine body condition and maximum size sharply decreased in almost all Mediterranean areas along years (only the Northern Alboran Sea denoted no decreasing trend for either species). While anchovy body condition was positively correlated to Eddy kinetic energy the sardine one rather depended on the chlorophyll-*a* quantity. By examining specific breakpoint time period, both species exhibited breakpoints toward low body condition values during 2000's, although no concomitant environmental breakpoint was detected. Analysis at large spatial scale also underlined the absence of a unique general pattern in body condition fluctuation in the Mediterranean Sea. Yet, subregions of approximately 900 kilometers where fluctuations are significantly correlated were identified.

Together, these analyses highlight the current poor body condition of almost all small pelagic fish populations in the Mediterranean. Due to its importance in fish energy allocation among the different life history traits, as already observed through reduced fish maximum size and low stock biomass, this prolonged poor fish body condition may have strong ecological, economic and social consequences all around the Mediterranean.

March 8, 14:40 (S1-11795)

A full-life-cycle multispecies IBM for Mediterranean small pelagic fish

A. Gkanasos, K. Tsiaras, S. Somarakis, M. Giannoulaki, A. Machias, E. Schismenou, G. Petihakis and George **Triantafyllou**[1]

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Anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) are the most important small pelagic fish in the Mediterranean regarding biomass and economic importance for fisheries. They play a key role in the food web and respond rapidly to environmental changes, given their short life span and feeding on planktonic organisms. During the past decades, there has been a decrease in both anchovy and sardine biomasses, mean size and somatic condition in many Mediterranean sub-basins. To study species interactions and better understand the responses of their populations to climatic variability, we developed a full-life-cycle, two-species population model that is two-way coupled with the POM-ERSEM hydrodynamic- biogeochemical model for the Mediterranean Sea. In this presentation, we demonstrate the structure and characteristics of the two-species model which is stage- /age-specific and includes bioenergetics, movement and reproduction modules, based on the best available biological knowledge on anchovy and sardine in the Mediterranean. A series of sensitivity experiments are conducted to better understand the role of changing environmental conditions (in particular temperature and river nutrient inputs) as well as changing fishing mortality on somatic growth, egg production and subsequent recruitment of the two species. In a next step, we make an effort to assess the strength of the interaction between sardine and anchovy. We focus on the between-species competition for food, especially in oligotrophic environments, and finally, on the likely predation of sardine on anchovy eggs and vice versa (intra-guild predation).

March 8, 15:00 (S1-11799)

Population changes in small pelagic fish of the Gulf of Lions: A bottom-up control?

Claire **Saraux**[1], Elisabeth Van Beveren[1,2] , Pablo Brosset[1,3], Sylvain Bonhommeau[1,4] and Jean-Marc Fromentin[1]

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Recently, a shift in the Gulf of Lions ecosystem has been observed with considerable changes in the three main small pelagic fish stocks (anchovy, sardine and sprat) in terms of biomass and fish mean weight. Surprisingly these changes did not appear to be mediated by changes in recruitment, which remained high, or by a too high fishing pressure, the exploitation rate being extremely low. First, the study of multiple population characteristics highlighted a decrease in body condition for all 3 species as well as an important decrease in size of anchovy and sardine resulting both from a slower growth and a progressive disappearance of old sardines. Interestingly, older sardines were more affected by the decrease in condition than younger ones, another sign of unbalanced population structure. Different hypotheses for these changes were investigated from bottom-up to top-down control, not forgetting epidemic diseases. A general veterinary study, aimed at detecting a wide range of potential pathogens, including parasites, viruses and bacteria detected very low prevalences apart from coccidian hepatic parasites, no clear damage to tissues and no link between pathogen presence and host size or condition. Top-down control by tuna or dolphins also showed to be a highly unlikely driver of recent changes, as the percentages of consumed population were estimated ≤ 2% and no size-selectivity was observed. Finally, mesozooplankton abundance was linked to sardine and anchovy condition and a dietary study exhibited important changes in isotopic values as well as in consumed plankton community and size from stomach content analyses. This suggests bottom-up processes as the main control of small pelagics in the NW Mediterranean, the current worrying situation resulting from changes in plankton, which remain to be investigated.

March 8, 15:20 (S1-11757)

Spatio-temporal modelling of Northeast Atlantic mackerel (*Scomber scombrus*) distribution: Introducing estimates of uncertainty and going beyond 'visual' correlations

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Spatio-temporal dynamics of pelagic fish are often approached through observing maps and visually identifying relationships between environmental factors and the species under question, lacking most of the times proper statistical support. Given that spatial (and often temporal) autocorrelation is extensively observed in the marine environment, usually referred to as 'patchiness' or 'schooling' (when it comes to fish), incorporating it into statistical models is highly relevant. In this presentation we implement state-of-the-art methods to statistically model the biomass distribution of the Northeast Atlantic (NEA) mackerel in the period from 2011 to 2016. In particular, we utilize INLA (Integrated Nested Laplace Approximation) techniques to identify the drivers of spatio-temporal fluctuations of the distribution of this stock. We test complex geostatistical models, incorporating a large suite of abiotic and biotic environmental factors, in a very flexible, efficient and primarily fast way with INLA (compared to standard Markov Chain Monte Carlo simulations), while simultaneously providing uncertainty estimates. Moreover, through accounting for abundance of prey and/or competitor species (e.g. herring), we explore possible density-dependent and/or resource competition mechanisms that might influence the observed distribution of mackerel. The INLA approach tackles efficiently common geostatistical and computational problems for 'big data', thus making it ideal to study the spatio-temporal patterns of resources of great ecological and economic importance, such as the NEA mackerel.

March 8, 16:00 (S1-11759)

Ocean-atmosphere interactions related to the AMO caused simultaneous 'regime shift'-like changes in ecosystems of eastern North Atlantic and Mediterranean in the mid-1990s

Jürgen **Alheit**[1], Joachim Groeger[2], Priscilla Licandro[3], Ian H. McQuinn[4], Thomas Pohlmann[5] and Athanassios C. Tsikliras[6]

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Northeast Atlantic marine ecosystems such as the Bay of Biscay, Celtic Sea, English Channel, Subpolar Gyre region, Icelandic waters and the North Sea as well as the Mediterranean show concomitant 'regime shift'-like changes around the mid-1990s, which involved all biota of the pelagial: phytoplankton, zooplankton, pelagic fish assemblages, demersal fish assemblages and top predators. These shifts were caused by complex ocean-atmosphere interactions initiating large-scale changes in the strength and direction of the current system that move water masses around the North Atlantic and involved the North Atlantic Oscillation (NAO), the Atlantic Meridional Overturning Circulation (AMOC), and the subpolar gyre (SPG). The contractions and expansions of the SPG most likely played a key role in the coupled atmosphere-ocean system of the North Atlantic. Fluctuations in the AMO seem to be a driver for these complex processes and small pelagic fish population trends were the sentinels of these mid-1990s changes.

March 8, 16:20 (S1-11703)

Will climate change impact the anchovy spawning habitat in the Bay of Biscay?

Maite **Erauskin**[1], Paula Alvarez[2], Haritz Arrizabalaga[2], María Santos[2], Andrés Uriarte[2], Leire Ibaibarriaga[1], Unai Cotano[2] and Guillem Chust[1]

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Climate change might trigger important shifts in the distribution, abundance, size and phenology of fish populations. The main objective of this study was to assess the importance of climate variability and change on anchovy (*Engraulis encrasicolus*) spawning habitat within the Bay of Biscay.

To address this objective, we combined time series and habitat modelling techniques. We first analysed the influence of the environmental factor such as the sea surface temperature on the total anchovy egg abundance and on the gonadosomatic index (GSI). Then, Generalized Additive Models (GAMs) were applied in order to build species habitat distribution models. Subsequently, distribution and phenology of anchovy spawning were projected to the end of the century (2080–2099) under the Intergovernmental Panel on Climate Change (IPCC) RCP8.5 climate scenario, using coupled hydroclimatic-biogeochemical models. Future states were compared to present (2001–2020) conditions and changes in anchovy distribution, abundance and phenology were evaluated.

Temperature, salinity and mixed layer depth were the main environmental drivers defining the present habitat distribution changes for anchovy spawning. Main results showed a projected overall increased density in anchovy eggs under future climate change scenario by the end of the century, with a northwestward expansion.

Keywords: Climate change, Bay of Biscay, anchovy, distribution shift, phenology

March 8, 16:40 (S1-11742)

Storytelling based on a data limited situation: Dynamics of a small pelagic community in the Northeast Atlantic

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Recent years have seen a change in the Northeast-Atlantic distribution of small pelagics. Species such as anchovy and sardine have increased in the northern parts of their distributional boundary, seemingly shifting from the Bay of Biscay to the Celtic Sea. Little is known on the distribution of these species in their northern border, with only limited information from a small scale fishery and 4 years of spatially-limited acoustic surveys. Conversely, bottom trawl surveys have been carried out at a larger spatio-temporal scale (from Scotland to the Gulf of Cádiz since the seventies) and, despite not being ideal to represent small pelagic species, might offer important insights on the situation. We aim at capturing the long-term spatial dynamics of these species and linking them to potential environmental drivers, using all the information available. Because data are patchy (different surveys/seasons) the different indices of abundance will be standardized through a geostatistical log Gaussian-Cox process model. For each species, spatial indicators (e.g. centre of gravity, inertia, convex hull) will be used to summarize the spatial changes through time. Artificial neural networks will be applied to: i) detect and characterize common trends at different sampling sites and geographical regions; ii) relate these trends to some environmental drivers. Moreover, standardized data will be modelled using the Dynamic Factor Analysis to assess and quantify the potential role of some environmental variables. These analyses will help to shed some light on the poorly known small pelagic community in the area, its spatial dynamic and environmental drivers.

March 8, 17:00 (S1-11173)

Expansion of Northeast Atlantic mackerel (*Scomber scombrus*) in the Nordic seas from 2007 to 2015 in relation to stock size and environmental conditions

Anna H. **Olafsdottir**[1], Kjell Rong Utne[2], Jan Arge Jacobsen[3], Teunis Jansen[4], Guðmundur Oskarsson[1], Leif Nøttestad[2], Cecilie Broms[2] and Aril Slotte[2]

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Northeast Atlantic mackerel (*Scomber scombrus*) is a highly migratory temperate fish that currently occupy the Northeast Atlantic from Gibraltar (36°N) to Svalbard (76°N). Mature individuals migrate annually between southern overwintering and spawning areas, and northern summer feeding grounds traditionally limited to Norwegian Sea (east of 10°W and south of 72°N) and North Sea. Catch-per-unit-effort from 2261 scientific trawl hauls in the summer feeding area from 1997 to 2015 revealed a six-fold increase in distribution range from 0.4 to 2.4 mill. km^2. The expansion began in 2007 and was in two directions: northward in the Norwegian Sea by approximately ~500km, and westward along the south coast of Iceland towards Greenland by approximately ~1200km. Mackerel distribution was delineated by temperature while zooplankton abundance did not have significant effects when testing with data sampled at each trawl station. Mackerel prefer temperatures ranging from 9°C to 13 °C (high occurrence and high density), tolerate temperature > 7°C (high occurrence but low density) but avoided waters < 5°C (absence). The apparent lack of a spatial relationship between mackerel and its prey was surprising and could be due to inappropriate sampling scale, grazing before sampling, or biased sampling of prey. However, this is a seasonal feeding migration where individuals collect energy for the annual over winter and spawning periods, hence, prey has to be a vital factor. The observed mackerel geographical expansion coincided with doubling in stock size but not with changing temperature.

March 8, 17:20 (S1-11729)

Norwegian spring spawning herring migration and feeding at the Arctic front

Webjørn Melle[1], Geir **Huse**[1], Aril Slotte[1], Espen Strand[1], Thor Klevjer[1] and Peter Wiebe[2]

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We observed herring horizontal and vertical distribution during feeding migration along a 125 nmi transect across the Arctic front of the Norwegian Sea in relation to its physical/biological environment, distribution of prey organisms and pelagic and mesopelagic competitors. High resolution ecosystem data were obtained by hull mounted multi-frequency acoustics and underway T, S and Chl, and a towed platform undulating between 0 and 400m equipped with multi-frequency acoustics, CTD-F, OPC and VPR. Additional sampling was done by MOCNESS and water bottles for nutrients and chlorophyll. Biological characteristics and stomach content of the herring were obtained from trawl samples. The Arctic front proved to be a strong barrier in zooplankton biomass, abundance and diversity. The front also formed a transition zone in phenology of phyto- and zooplankton, being delayed on the cold side. The herring were distributed all along the transect showing a shallow distribution on the warm side and both deep and shallow on the cold side, not related to light and time of the day. Its stomach content was higher on the cold side. There was no significant pattern in average age, weight or body length of the herring along the transect. We observed an inverse relationship between biomass of potential prey and herring indicating a negative effect of herring feeding on zooplankton biomass. However, based on stomach content and stomach evacuation rates in relation to prey biomass, the herring did not seem to have a strong top-down effect on its prey on the spatial scale of our observations.

March 8, 17:40 (S1-11919)

Multidecadal climate signal and its association with the Nordic Seas pelagic fish complex and their zooplankton prey

Svein **Sundby** and Webjørn Melle

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The primary production (PP) of the Nordic Seas is strongly seasonally pulsed due to the extreme seasonal light cycle in this high-latitude ecosystem. The endemic herbivorous copepods are adapted to the seasonal PP by rapid spring and early summer growth with lipid accumulation, and overwintering at large depths. The three major pelagic fishes, Norwegian spring-spawning herring (NSSH), the Atlantic mackerel (AM), and the blue whiting (BW), are all predators on herbivorous copepods. They have adapted to the pulsed plankton production by intensive spring and summer feeding in the upper layers, and retreat to other regions during winter. NSSH has copied the seasonal cycle of the copepods by overwintering locally at greater depths, while AM and BW that have greater migration potentials retreat farther south in the North Atlantic where winter production is high enough for active feeding. Zooplankton biomass increased in the Norwegian Sea from cool 1960s to around 2000, parallel to the warming of the ocean in the region. While the ocean warming continued and culminated around 2007, zooplankton biomass dropped rapidly from 2000 to 2009. We discuss whether the drop in zooplankton biomass is caused by the increasing biomass of the three pelagic predators that culminated and leveled out around 2007, indicating a potential carrying-capacity level of pelagic fishes in the Norwegian Sea. Moreover, we discuss whether such rapid response to changes in climate could cause top-down control and further become the cause of the historically well-know “herring periods”.

SESSION 1, DAY-4, March 10

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

March 10, 09:00 (S1-11756)

Tendency for climate synchrony and amplification in global fish populations

Emanuele **Di Lorenzo**[1], Mark D. Ohman[2], Salvador Lluch-Cota[3], Christopher Costello[4] and Steve Gains[4]

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Fish populations around the world exhibit an apparent temporal synchrony and amplification of small-amplitude global climate signals. Whether this apparent synchrony reflects a true climate and ecosystem mechanism or just a random coincidence remains unclear. We present a simple theory which predicts that fish populations exhibit a natural tendency to synchronize their variability with global-scale low-frequency changes of the climate system. Previous work shows that double integration of white noise atmospheric forcing by the ocean (1x integration) and subsequently by the biology (2x integration) can explain the emergence of strong transitions and prolonged state changes in marine population. We expand the double integration model to simulate fish species that are sensitive to multiple independent regional forcing functions. We show that if the different forcing functions have a small imprint (e.g. 5-10%) from global-scale climate variability or climate change signal, the double integration acts as a powerful filter that amplifies the common signal leading to climate synchrony among the fish population. This theory is consistent with the low-frequency variability observed in global fish stock from a comprehensive and quality control FAO fish dataset from FAO with over 400 species.

March 10, 09:20 (S1-11714)

Reproducing migration history of Japanese sardine using otolith $\delta^{18}O$ and a data assimilation model

Tatsuya **Sakamoto**[1], Kosei Komatsu[1,2], Kotaro Shirai[1], Yasuhiro Kamimura[3], Chikako Watanabe[3], Atsushi Kawabata[4], Michio Yoneda[5], Toyoho Ishimura[6], Tomihiko Higuchi[1], Takashi Setou[3] and Manabu Shimizu[3]

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A new method to reproduce migration histories of Japanese sardine (*Sardinops melanostictus*) was developed by using the combination of otolith oxygen stable isotope ratio ($\delta^{18}O$) and a data assimilation model. Firstly, rearing experiments for three different temperatures were conducted for a month and otolith $\delta^{18}O$ were analyzed. A linear relationship between otolith $\delta^{18}O$ and temperature was determined for the first time for Japanese sardine as follows: $\delta_{otolith}=\delta_{water}-0.181*Temperature+2.690$, $r^2=0.91$ (1). Secondly, seawater $\delta^{18}O$ and salinity in the western North Pacific were revealed to be strongly correlated from *in situ* samplings: $\delta_{water}=0.5951*Salinity-20.347$, $r^2=0.89$ (2). Micro-volume $\delta^{18}O$ analysis and our original micro-sampling technique enabled us to extract otolith $\delta^{18}O$ profile in a temporal resolution of 10-15 days through whole life of juveniles approximately 200 days post hatch. For the dates corresponding to each value of the profile, surface temperature and salinity in the range of 30-55N, 130-180E were extracted from a data assimilation ocean model FRA-ROMS which reproduces ocean environment realistically. Temperature and salinity in each grid were converted into otolith $\delta^{18}O$ value using Eq. (1) and (2). Grid points in which the calculated otolith $\delta^{18}O$ value was equivalent to actually analyzed one were considered to be the location of the individual on the date. Movements of the juveniles reproduced by this method clearly showed the northward migration from the Kuroshio-Oyashio transition zone to the Oyashio region and the estimated location on the sampling week approached to the actual sampling point, which indicated the high accuracy of the method.

March 10, 09:40 (S1-11952)

A story starting from the wind: A synthesis of the collapse of Japanese sardine stock

Hiroaki **Saito**[1] and SUPRFISH scientists

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Fish species alternation (FSA) between sardine and anchovy is a drastic example of ecosystem regime shift responding to climate change. Sardine stock level off Japan was > 10^7 ton in 1980's. After 1988, the continuous failure of the recruitment collapsed the stock down to 1~2x10^5 ton (2000's). Japanese interdisciplinary project SUPRFISH (Studies on Prediction and Application of Fish Species Alternation) revealed the stock collapse was a result of the physical oceanographic change in the Kuroshio Extension (KEX) region which starting from the wind north of Hawaii. Change in wind forcing in the central and eastern North Pacific induced high SSH anomaly in 1984, which was propagated to west by Rossby wave, and reached to KEX in 1987/88. The high SSH anomaly enforced the Kuroshio and KEX, increased winter time temperature and shallowed winter mixing layer in the KEX, which induced mismatch between plankton production and larval/juvenile sardine arrival to the region. The sudden stock collapse damaged the regional economy depending on sardine fishery, such as Kushiro, Hokkaido. It is expected that the monitoring of the Rossby wave propagation of SSH and sardine larvae/juvenile provides an early warning for fishers and managers.

March 10, 10:00 (S1-11704)

Prospects of a new "sardine epoch" in the Northwest Pacific

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Japanese sardine, *Sardinops melanostictus*, is a highly-fluctuating species with considerable changes in its biomass and abundance. In the XX century the Japanese fishermen have recorded two periods of high sardine catches: 1925-1941 and 1973-1994. The "sardine epochs" are associated with appearance of a series of strong generations under favorable environmental conditions for high survival of their larvae and juveniles in the subtropical and mixed waters. These conditions are commonly observed during the decades-long climatic periods with predominance of negative SSTA in the Northwest Pacific, demonstrating establishment of the "subarctic hydrometeorological regime" in the Kuroshio-Oyashio ecosystem (EKO). A new rise of sardine abundance noted in 2010-2015 after a decades-long pause, was associated with relatively strong year classes formed as a result of surface water cooling in the EKO area due to local strengthening of winter cyclonic activity. However, this growth of biomass and catches does not correspond to exponential curve typical for "sardine epochs". The strong 2015-2016 El Niño event resulted in positive SSTA in areas of sardine larvae and juveniles feeding in winter of 2016. It may be expected that similar "warm" conditions will continue in winters 2017-2018 that results in rapid decrease in sardine stock and catches after 2017. Our analysis of the long-term variability of winter atmospheric circulation and thermal conditions of the North Pacific indicate the possible beginning of the next "sardine epoch" in the late 2020s – early 2030s.

March 10, 10:20 (S1-11812)

From physical mechanisms to natural fluctuations of small pelagic fishes: The Angolan upwelling scenario

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In situ data from acoustic surveys and satellite imagery (1994-2014) are used to describe upwelling and drift patterns within the essential habitat of the Angolan sardinella (6° - 12°30'S). Ocean climate is in this region controlled the Tropical Atlantic Variability (TAV). Local upwelling (downwelling) favorable conditions are induced by the thermocline elevations (depressions) transmitted from the equator in the coastal waveguide. The austral winter upwelling season continues from June to August. Algal blooming, planktonic food concentrations and high densities of sardinella occur in the depth range 20-60 m, in connection with internal tide fronts. The onset of the spring downwelling season (September to November) sees the stratification strengthen and thermocline depressed. A poleward intrusion of low-salinity tropical water develops at the sea surface. The associated current serves as a transport mechanism for larvae and juveniles developed during the preceding upwelling season to reach nursery areas downstream. The tidal fronts vanish from the coast, repelling sardinella offshore. Late November sees the end of the spring downwelling and marks the beginning of the second semi-annual upwelling-downwelling cycle, which continues until April. In contrast to the winter-spring cycle, the minor upwelling in December-January and downwelling in February to April exhibit strong interannual variability, controlled by the TAV. There are no in situ observations in the sardinella habitat during the minor upwelling. During the fall downwelling season, the TAV forcing induces interannual variations in strength, timing and duration of the poleward current episodes. The effect on sardinella, observed during 1994-2014 inclusive of the strongest Benguela Niño episodes, was transient; affected fish behavior but not the population structure. As the coastal climate is warming, the population of the Angolan sardinella within its main habitat is rising. We attribute this to the climatologically stable conditions during the critical main upwelling season and a moderate fishing pressure.

March 10, 11:00 (S1-11875)

Patterns in chub mackerel abundance and distribution in relation to environmental conditions

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Chub mackerel (*Scomber colias*) is a fish with pelagic habits which distributes in depths from 250 to 300 m in warm and temperate waters of the Atlantic Ocean and in the Mediterranean Sea. Although normally caught as a by-catch in purse seine fisheries that target sardine, this species has gained economic importance in recent years due to the scarcity of sardine and became a target of purse seiners in several Portugal southern ports. Landings in Portugal and Spain have almost tripled since the early 2000's, possibly due to a combination of increased commercial interest, new markets and the dramatic decrease of sardine in the area. Time series data collected during 10 years (2005-2015) in demersal and acoustic surveys off the Portuguese coast show that chub mackerel occurs differently along the years and latitudes in high densities and patches.

Environment variables (e.g. area, depth, temperature) are related to chub mackerel abundance and distribution using integrated models dealing with considerable proportion of stations with zero catch by modelling the probability of catch (presence/absence) and the amount of positive catch rates. Patterns of abundance and distribution are discussed also considering the species growth and reproductive traits. We expect this study to contribute for a better understanding of chub mackerel biology in a pelagic environment.

March 10, 11:20 (S1-11848)

Spatial time series analysis of the small pelagic fish on the shelf north of Cap Blanc within its upwelling ecosystem

Najib **Charouki**[1], Omar Ettahiri[1], Amina Berraho[1], Mansour Serghini[1], Gabriella Bianchi[2] and Marek Ostrowski[3]

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The small pelagic resources on the North West African shelf are among the largest pelagic stocks in the world with a standing biomass that exceeded 6 million tons in 2015 (CECAF 2015). These stocks are exploited at different levels and regularly assessed. Monitoring of these resources through fisheries independent surveys has been carried out by the Norwegian R/V "Dr. Fridtjof Nansen", with national research vessels and with the Russian R/V "AtlantNiro". In addition to assessing biomass, size composition and other biological parameters, these surveys also include environmental sampling such as for physical parameters (oceanography) and plankton. The results show that small pelagic fish has consistent spatial trends but is subject to considerable seasonal and inter-annual fluctuations in biomass, with periods of growth followed by major declines that cannot be explained as a result of fishing pressure. A correlation analysis was carried out between spatial indicators of the main small pelagic stocks with environmental and plankton indices as potential factors explaining the stock dynamics and trends.

March 10, 11:40 (S1-11765) CANCELLED

Relationship between abundance of small pelagic fishes and environmental factors in the CanC an analysis based on hydroacoustic and satellite data

M. Ahmed **Jeyid**[1], M. Bacha, D. Dessailly, V. Vantrepotte and R. Amara

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From 1995 to 2006, acoustic surveys were conducted yearly during the months of October to December to assess the abundance of small pelagic fish species off NW Africa. Generalized additive models were used to identify major environmental factors that affect the distribution and abundance of anchovy, sardine, and sardinella. Species abundance was used as the response variable and environmental (SST, IUC, WMI, IRC and Chl-a), spatial-temporal variables were used as the predictor variables. The study area was characterized by pronounced latitudinal and interannual variations in environmental conditions during the period of study. Sardine has the highest biomass followed by sardinella and anchovy. Anchovy and sardine were found between 20°-34°N whereas sardinella was recorded only in the southern part of the studied area between 24°-11°N. There was interannual variations in the center of gravity of species distribution, with a northward or southwards shifts. Among the environmental parameters studied, temperature was the main parameters explaining spatio- temporal variations of species abundances. Sardine abundance increase with upwelling intensity whereas anchovy and sardinella were associated with low upwelling index. This study suggest that anchovy and sardinella spatio-temporal variations off NW Africa is more controlled by thermal than productivity gradients, whereas sardine seem to be more controlled by an "optimal upwelling and temperature" windows. For the first time, alternating population fluctuations between anchovies and sardines were observed off NW Africa.

March 10, 12:00 (S1-11780)

Population traits in small pelagic fish model: Emergence from interactions between a turbulent upwelling environment and individual behaviors in upwelling systems

Timothée **Brochier**[1], Pierre-Amaël Auger[2], Laure Pecquerie[3], Eric Machu[2,5], Xavier Capet[8], Modou Thiaw[4], Baye Cheikh Mbaye[5], Cheikh-Baye Braham[6], Omar Ettahiri[7], Najib Charouki[7] and Patrice Brehmer[3,4]

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8 LOCEAN, IRD, CNRS Université Pierre et Marie Curie, Paris, France

Small pelagic fish (SPF) species are heavily exploited in the four main eastern boundary upwelling systems (EBUS) as their transformation are increasingly used in the world food chain. Management relies on regular monitoring, but there is a lack of theory for population traits emergence and evolution in a rapidly changing and challenging environment. We address this gap by combining state of the art physical and biogeochemical modeling with an individual life cycle based model, applied to the round sardinella (*Sardinella aurita*, Clupeidae) population off Northwest Africa.

Our analysis focused on the processes responsible for seasonal migration, spatio-temporal body-length distribution, and interannual biomass fluctuations. Emergence of preferred habitat resulted from complex interactions between natal homing behavior and environmental variability that impact early life. Individual exploration of the environment was determined by swimming capacities, the mesoscale structure of the habitat and the horizontal currents.

Observed spatio-temporal abundance variability emerged from a superposition of numerous distinct individual life histories. Simulations also suggested an alongshore gradient in size distributions confirmed by in situ measurements. New insights about population structure are provided, with a focal area in Mauritania and mainly two migrating subpopulations respectively centered at 18°N and 21°N. Interannual biomass fluctuations were linked to variability in Sahara Bank's fish recruitment, itself depending on southward current intensity.

The identified processes constitute an analytical framework that can be transposed to study SPF in others EBUS and used to make prospective of the impact of regional climate change.

Session 2
Oral Presentations

External drivers of change in early life history, growth and recruitment processes of small pelagic fish

SESSION 2, DAY-1, March 6

External drivers of change in early life history, growth and recruitment processes of small pelagic fish

March 6, 14:10 (S2-11727), Invited

Revealing the link between prey availability during the larval stage and recruitment strength in small pelagic fish

Dominique **Robert**[1], Carissa J. Wilson[2], Daigo Kamada[2] and Hannah M. Murphy[3]

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Populations of small pelagic fishes are characterized by boom-bust dynamics driven by massive interannual recruitment variability encompassing several orders of magnitude. Variability in year-class strength primarily depends on survival during the first few weeks of life in the plankton when larvae are particularly vulnerable to starvation and predation. Suboptimal feeding conditions during this critical phase of the life cycle are expected to result in slow growth and high mortality. Despite the importance of this assumption, few studies have revealed a direct link between secondary production and recruitment of small pelagic fishes. It was recently proposed that the failure in detecting a link between larval survival and zooplankton abundance is attributable to the generally low taxonomical resolution of larval diet, strongly limiting our knowledge of the actual prey field. In the present contribution, the link between year-class strength and the availability of prey during the larval stage is explored in populations of small pelagic fishes based on the prior detailed description of larval diet. Results obtained with Atlantic mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*) and capelin (*Mallotus villosus*) populations in the Northwest Atlantic support the hypothesis that larval feeding, growth and survival are controlled by the availability of preferred prey. A precise definition of prey field based on high taxonomical resolution of larval diet may facilitate the effective assessment and management of small pelagic fish resources.

March 6, 14:40 (S2-11758)

Impact of seasonal environmental variability on the bioenergetics strategy of anchovy and sardine: A combined data and modelling study in the Bay of Biscay

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A growing amount of literature aims at explaining the distinct population dynamics of anchovy and sardine by specific responses to biotic and abiotic factors through slightly distinct biological traits, e.g. temperature preferenda or feeding behaviour. Integrative approaches are then required to understand the respective and combined impacts of such factors. A bioenergetics approach aims at quantitatively assessing energetic condition and energy fluxes within an organism from energy acquisition (feeding), to storage and latter allocation (to soma or reproduction). To compare anchovy and sardine, we considered both energy density (Ed) measurements and Dynamic Energy Budget (DEB) modelling. Data analysis first showed large differences in absolute Ed values and seasonal magnitude, likely reflecting a higher storage capacity for sardine. Size, age and ontogeny strongly affect Ed values, highlighting increased storage capacity during the first years of life. DEB models for both species were calibrated and species compared on the basis of model parameters and predictions. We showed that bioenergetics strategies of both species differ in terms of energy acquisition, storage capacity and later allocation for both growth and spawning. In this context the spawning phenology appears to be strongly interlinked with specific bioenergetics strategies. Overall, our results showed that anchovy has an almost "all or nothing" energy allocation strategy, while sardine shows lower and more regular metabolic activity throughout the year. Such bioenergetics approaches could, in a near future, offer a framework to further investigate specific responses of both species to external drivers.

March 6, 15:00 (S2-11890)

Testing the reliability of species distribution models: How stable are relationships between small pelagic fishes and oceanographic conditions in the southern California Current ecosystem?

Rebecca G. **Asch**[1,2,3], Keo Chan[1] and Joanna Sobolewska[1]

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Species distribution models are an important tool for projecting changes in the occurrence, abundance, and phenology of marine organisms under climate change. A fundamental, but often untested, assumption of these models is that relationships between organisms and the environment are stationary. When tested, species distribution models for phytoplankton and zooplankton have performed poorly when using data from one decade to project changes during other decades. It is unknown whether this finding can be extended to other trophic levels. We examined this by developing generalized additive models (GAMs) to test whether environmental variables that influence four small pelagic fishes (*Sardinops sagax*, *Engraulis mordax*, *Trachurus symmetricus*, *Scomber japonicus*) remained steady between the cool and warm phases of the Pacific Decadal Oscillation (PDO) in the southern California Current ecosystem. We included temperature, salinity, dissolved oxygen, and mesozooplankton volume as predictor variables in our model of larval fish occurrence. Relationships between larvae, oxygen, and salinity were stable between PDO phases, but subtle changes occurred in the relationships between larvae, temperature, and zooplankton. *S. sagax*, *E. mordax*, and *S. japonicus* exhibited more pronounced temperature preferences during the warm-phase PDO. This PDO phase was characterized by reduced secondary production, which caused the GAMs to project that *S. sagax* and *E. mordax* larvae were associated with lower zooplankton volume during the warm-phase PDO. However, the two mackerel species occurred at sites with high zooplankton volume during this PDO phase, suggesting that the larger, more mobile mackerel species can actively seek out spawning grounds in biologically productive habitats.

March 6, 15:20 (S2-11708)

Environmental drivers of peak recruitment years of Norwegian Spring Spawning Herring (*Clupea harengus* L.)

Øystein **Skagseth**, Aril Slotte, Erling Kåre Stenevik and Richard Nash

Institute of Marine Research, Bergen, Norway

Norwegian Spring Spawning herring (NSSH) *Clupea harengus* L. spawn on coastal banks along the west coast of Norway. The larvae are generally transported northward in the Norwegian Coastal Current (NCC) with many individuals utilizing nursery grounds in the Barents Sea. The recruitment to this stock is highly variable with a few years having exceptionally good recruitment. The principal causes of recruitment variability of this herring population have been elusive. Here we undertake an event analysis using data between 1948 and 2013 to identify the physical conditions in the NCC that coincide with years of high recruitment. Contrary to the climatological upwelling favorable winds from northeast, the years with high recruitment coincide with predominantly southwesterly downwelling winds in spring and summer, effectively enhancing the northward coastal current during the larval drift period. Also in most peak recruitment years, low-salinity anomalies are observed to propagate northward during the spring and summer. It is suggested that consistent southwesterly winds and propagating low-salinity anomalies, both leading to an enhanced northward transport and retention of larvae in the coastal waters, are important factors for elevated recruitment. At the same time, these conditions stabilize the coastal waters, possibly leading to enhanced production and improved feeding potential along the drift route to Barents Sea. Further studies on the drivers of early life history mortality can now be undertaken with a better understanding of the physical conditions that prevail during years when elevated recruitment occurs in this herring stock.

March 6, 16:00 (S2-11700)

Oceanographic conditions and runoff from Congo River as drivers for *Sardinella* recruitment off south-western Africa

Jens-Otto Krakstad[1], Espen Bagøien[1], Tor Ensrud[1], Jean de Dieu Lewembe[2], Domingas N'saku[4], Jean Samba[3] and Øystein **Skagseth**[1]

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Sardinella aurita and *S. maderensis* represent important pelagic fish stocks off western Africa. This study focuses on recruitment of *Sardinella* in a coastal ecosystem influenced by fresh water from Congo River that forms a massive northwest slanted surface plume. Two surveys were made with R/V Dr. Fridtjof Nansen about May: 2014 (Gabon - northern Angola) and 2016 (Gabon - northern Congo). Despite a highly variable oceanographic environment, seasonally and spatially, the main distributional patterns for nutrients, plankton, and *Sardinella* eggs and larvae were surprisingly similar the two years. Nitrate, phosphate and chlorophyll concentrations in upper waters were enhanced in the border area off Gabon-Congo downstream of the Congo River outlet, decreasing northwards (nutrient data only for 2016). Sardinella spawned in the river plume and *Sardinella* eggs and larvae were mainly encountered in the same area with increasing larval size north of the highest egg concentrations, ca. 4-5°S. In 2016, *Sardinella* larvae were also observed further north. We suggest that the Congo River plume represents a hotspot for *Sardinella* reproduction, and that the spawning of *Sardinella* centred about May coincides with relatively low Congo River outflow and the maximum of the Equatorial Under Current, the source for the Gabon-Congo Under Current. We hypothesize that the nutrients supply in this period is still sufficient for new primary production, and that the intermittent Gabon-Congo Under Current plays a role in retaining the *Sardinella* larvae within the shelf area of high primary production, before the larvae reach the nursery ground in southern Gabon.

March 6, 16:20 (S2-11829)

Fast growth and early age-at-recruitment of the anchovy (*Engraulis ringens*): Evidence from interannual monitoring of otolith microstructure in northern Chile

Guido **Plaza**[1] and Francisco Cerna[2]

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The Peruvian anchovy (*Engraulis ringens*) play a key ecological role in the Humboldt Current System (HCS), as prey for others fishes, marine mammals and sea bird. Furthermore, this species support an important fishery activity in Perú and Chile representing a substantial fraction of the global anchovy fisheries. However, many aspects of its early life history traits are poorly understood yet. In the current study an interannual analysis of age and growth for juveniles and adults was performed using otolith micro-structure analysis. At first validation of the daily periodicity of micro-increments was confirmed by using chemical marking in rearing experiment and analytical procedures in wild fish. Irrespective of year where survivors were exposed to variable environment conditions, early recruits appearing in the fishery (9-12 cm TL) were originated from spawning events occurring between three and five months earlier. Fast growth seemed to expand beyond the immature stage because a complete sequence of micro-increments was obtained from the primordium to otolith edge even in fish up to 15 cm LT. At the intra-annual scale, irrespective of monthly cohort the maximum growth occurred through the second month of life, although was enhanced in warmer months. These findings suggest *E. ringens* in northern Chile seems to maximize growth in the first year of life. As fishery length structure is mainly concentrated around 14 cm LT, most fish are removed at very early ages. A comprehensive evaluation of the implications these results would have for stock assessment and management of this species is highly recommended.

March 6, 16:40 (S2-11550)

Quantifying interannual variability in growth and condition of juvenile Pacific herring (*Clupea pallasii*) in the Strait of Georgia, BC

Emma **Pascoe**, John Dower, Tom Iwanicki and John Taylor

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Pacific herring (*Clupea pallasii*) is an ecologically and culturally significant forage fish in the NE Pacific. Although numerous studies have focused on adult and larval Pacific herring, the juvenile stage has been largely overlooked. In particular, the extent to which variability in the growth and condition of juvenile herring may affect the food quality that they represent to their predators remains unknown. Here we quantify variability in juvenile Pacific herring growth and condition in the Strait of Georgia from 2013-2016 using four proxies: Fulton's K, RNA:DNA ratios, otolith microstructure, and lipid analysis. The RNA:DNA ratio in animal tissue can provide an estimate of growth over short time periods, and is thus a good proxy for condition. RNA:DNA values in juvenile herring were higher in September 2013 compared to September 2015, while Fulton's K remained unchanged between the two years. A negative correlation between RNA:DNA values and size was observed when all herring were pooled.

These results may reflect this negative correlation, as herring from September 2013 were smaller. These results may also reflect a decrease in the metabolic condition of juvenile herring over time. Anomalously warm waters have been observed in the North Pacific from 2014-2015 and may have contributed to variability in growth rates and feeding success by altering the physiological responses of Pacific herring and the distribution of their prey. Otolith microstructure and lipid analyses will be used to supplement these findings and provide additional insight into patterns of interannual variability in juvenile Pacific herring growth and condition.

March 6, 17:00 (S2-11778)

Mackerel predation on herring larvae during summer feeding in the Norwegian Sea

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In the course of the past two decades, Atlantic mackerel, *Scomber scombrus*, have expanded their summer feeding distribution in the Norwegian Sea substantially, and now potentially overlap with pelagic larvae of Norwegian spring-spawning herring, *Clupea harengus*, as these drift northwards. Mackerel are known to be opportunistic predators, and the aim of this study was to evaluate mackerel predation in an area of overlap between mackerel and herring larvae, with particular focus on size selective predation on herring larvae. In early June 2013, we followed a predefined transect in the expected core larvae distribution area on the Norwegian coastal shelf between about 66°N and 69°N. The transect was conducted twice, and samples of mackerel for stomach analyses and subsequent herring larvae samples were obtained at pre-defined stations. Calanoid copepods were the dominant prey of the mackerel, but 45% of the mackerel guts contained herring larvae. The results suggest that mackerel fed opportunistically on herring larvae, and that predation pressure therefore largely depends on the degree of overlap in time and space. Furthermore, the results suggest that mackerel in the area preyed upon larger and older herring larvae as compared to the larvae sampled from the sea, contrary to the expectations from the "bigger-is-better" hypothesis.

March 6, 17:20 (S2-11628)

Effects of Atlantic mackerel predation on early life stages mortality of anchovy and sardine

Eneko **Bachiller**, Elsa Cuende, Almudena Fontán, Naiara Rodríguez-Ezpeleta and Unai Cotano

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Intraguild predation between small pelagic fish as regulation mechanism of early life stage survival may have a significant effect on inter-annual variations in fish abundance and recruitment variability. For instance, although traditionally linked to physical (e.g. transport, retention) processes, survival of anchovy early life stages in the main spawning grounds of the Bay of Biscay is partly regulated by small pelagic fish predation. Visual identification of adult fish stomach contents may underestimate early life stage mortality due to predation; indeed, preliminary genetic based prey identification suggests new potential predators such as mackerel larvae potentially feeding on anchovy and sardine eggs in the shelf break, where they could have been transported by advection. However, the role of different life stages of mackerel as potential predators and the relevance of their co-occurrence in the anchovy and sardine main spawning and nursery areas for early life stages survival and recruitment, remain unclear. This study combines both microscope and genetic based prey identification to provide more accurate estimates of anchovy and sardine early life stage mortality due to predation by mackerel larvae and adults. In addition, egg and larvae transport is considered as a potential factor that may regulate the effects of the intraguild predation, increasing or decreasing the prey-predator encounter rates. This study provides new insights into the trophic interactions in the Bay of Biscay, which is critical to inform advanced multispecies ecosystem models.

SESSION 2, DAY-2, March 7

External drivers of change in early life history, growth and recruitment processes of small pelagic fish

March 7, 10:40 (S2-11737)

Climate change as a causative factor in sustained reduced recruitment in Norwegian spring-spawning herring

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Assessments show that the recruitment to the Norwegian spring-spawning (*Clupea harengus* L.) has remained low since 2004. To elucidate why recruitment has persisted in being low a number of potential drivers have been investigated. Long time series of estimated recruitment to the Norwegian spring-spawning herring and the mean winter temperature at the Kola section in the Barents Sea showed a significant positive correlation for the period 1921 to 2004. From 2005 onwards, the positive correlation did not continue as the winter temperature increased to high levels while recruitment has remained low. Further investigations show that zooplankton biomass per m^2 dropped significantly after 2005 at the time when the larvae drift from the spawning sites. In the ten-year period after 2005, the zooplankton biomass has been half the level of the prior ten-year period. In addition, the composition of the zooplankton has changed. Satellite data indicate that for the same period, there has been a shift in the onset of the spring phytoplankton bloom in the core areas of the spawning of the herring stock resulting in an earlier zooplankton bloom. This shift can explain the reduction in zooplankton biomass, hence resulting in environmentally poorer conditions for the feeding of the larvae making the larvae more prone to predation. The change in composition of the zooplankton community at the time when the herring larvae feed confirm the shift to earlier spring bloom and there seems to be a mismatch between the presence of herring larvae and available food for the larvae.

March 7, 11:00 (S2-11534)

Influence of temperature and food availability on anchovy (*Engraulis encrasicolus*) dynamics as seen through a Dynamic Energy Budget (DEB) model

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Dynamic Energy Budgets (DEBs) developed by Kooijman (1993, 2001) are useful tools for describing the flow of energy from food assimilation to maintenance, growth, development and reproduction as functions of the environment (i.e. food density and temperature) for individual organisms. The objective of this study was to investigate the effect of environmental conditions on an individual anchovy (*Engraulis encrasicolus*) in terms of the energy available for growth and reproduction throughout the life cycle of the fish. Since anchovy is such an economically important part of small pelagic fish catches in South Africa. DEB theory has successfully been used to describe the growth and reproduction of both Bay of Biscay and Mediterranean anchovy since it allows for the identification of the specifics and common processes of each life stage. The parameters applied to the DEB model were estimated from published literature and available fisheries data. This DEB model forms the base for creating models for other small pelagic fish in the Benguela, such as sardine and redeye, and can then be applied to a varying food environment to see how these different species will compete for resources as they grow and reproduce. These models can also be useful in predicting how temperature changes affected by climate change may affect the growth and reproduction of these species.

March 7, 11:20 (S2-11883)

Historical fluctuations and recent observations of Northern Anchovy in the Salish Sea

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The Salish Sea (Strait of Georgia, British Columbia and Puget Sound, Washington) is a highly productive estuarine ecosystem with several important commercial, recreational, and cultural species. Historical and archeological data suggest that Northern Anchovy (*Engraulis mordax*) were at least periodically abundant in the Salish Sea; however, they have likely been scarce in recent decades. Since 2014, there has been increased frequency and abundance of Northern Anchovy catches in monitoring programs as well as increased frequencies of incidental observations, with accounts of anchovy appearing in the diets of valuable and depressed salmon stocks. We will present a review of historical and recent data on the biology and dynamics of Northern Anchovy in the Salish Sea. We will discuss these data in the context of local ecosystem changes and broader scale shifts in the Northeast Pacific. Potential implications of changes in Northern Anchovy abundance for the Salish Sea ecosystem will be discussed along with avenues for future research.

March 7, 11:40 (S2- 11796)

Validation of daily increments in the otoliths of Atlanto-Iberian sardine larvae (*Sardina pilchardus* Walbaum, 1792) reared at three different temperatures

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Daily increment deposition in otolith microstructure was analyzed in sardine (*Sardina pilchardus)* larvae reared in the laboratory under different temperatures (13°C, 15°C and 17°C), with a diet rich in microalgae, rotifers and copepods *Acartia grani* (3-5 prey L^{-1}). The number and width of growth increments, first-check ring and otolith diameter were determined in the otoliths and then related to larval age and total length. At hatching, the sagittae otoliths consisted of a lenticular core with diameter of 10.56 μm (± 1.07 μm SD) and a first check ring was formed with a diameter of about 10.81 (± 2.15 μm SD). Somatic growth increased with increasing temperature and the otoliths of larvae reared under different temperatures show significant differences between them. At 17°C, otoliths exhibited higher diameter with wider increments and greater number of counts while under 13°C otoliths showed the lowest values. The relation of increment count *vs* age for all temperatures showed an apparent growth deposition of less than 1 per day, and increasing with temperature. Observations and measures with SEM confirmed that increments are deposited daily but have an average width bellow 1μm, making therefore being hard or impossible to distinguish with light microscopy. The increased discrepancy of the increments number and real larvae age probably due to thinner and less marked increments at colder water temperatures and lower growth rates can lead to incorrect age determinations, showing the importance of being cautious when aging (or using field data of) young and/or slow growing clupeoid larvae.

March 7, 12:00 (S2-11770)

Larval capelin dynamics in coastal embayments of eastern Newfoundland

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Larval success is crucial to recruitment, and changes in recruitment affect subsequent year-class strength, which impacts fisheries and fishery management. Consequently, knowledge of early life dynamics is important as it allows for a better understanding of population dynamics. The waters off the eastern coast of Newfoundland, including Notre Dame Bay, White Bay, and Trinity Bay, are important spawning grounds for several commercially and ecologically important fishes, including capelin (*Mallotus villosus*), a small pelagic forage fish that transfers the bulk of the energy from lower trophic levels to top predators. While larval capelin are surveyed on an annual basis in Trinity Bay and considered as an index for the whole stock, larval dynamics in the northerly White Bay and Notre Dame Bay have been little studied. It thus remains unsure how representative the Trinity Bay larval survey is relative to the whole stock. In this study, we aim to provide a first test of the robustness of the current larval index by comparing the abundance, length and age frequency distributions, and growth rates of larval capelin in both areas. Plankton tows were conducted during the summers of 2015 and 2016, from which capelin larvae were extracted, measured, and their abundance determined. Larval age and growth rate were derived from otolith microstructure analysis. This comparison of larval capelin dynamics among bays of the eastern coast of Newfoundland will allow for a better understanding of the population dynamics of this key forage species of the Northwest Atlantic marine ecosystem.

March 7, 12:20 (S2-11773)

Does the early bird catch the worm? Shifts in the spawn timing of Pacific herring (*Clupea pallasii*) in Puget Sound, USA, and consequences for local abundance trends

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Pacific herring (*Clupea pallasii*) are foundational in the social-ecological system along the West Coast of North America, owing to their ecological, economic, and cultural importance. In the Puget Sound estuary in Washington, USA, Pacific herring are an indicator species, and the regional management agency has set recovery targets to guide herring management. Puget Sound herring are spatially and temporally segregated into individual subpopulations by their spawning behavior, and these individual "stocklets" show asynchronous abundance trends over the past several decades. While the Puget Sound herring stock as a whole shows variable but largely stable biomass through time, some local spawning subpopulations have significantly declining trends. My research focuses on identifying potential limitations on herring recovery to inform recovery targets and potential management strategies for reaching them. Over the past 4 decades, spawn timing has shifted in many of the Puget Sound herring stocklets, with some spawning earlier and some spawning later. Such shifts in spawn timing may have deleterious effects on stocklet recruitment, if larvae and juveniles lack access to appropriate prey at the appropriate time and location. Here, I will evaluate the potential role of environmental covariates, including temperature, salinity, water quality, and ocean conditions, in the observed shifts in spawn timing to address whether changes in spawn timing are driven by local, regional, or oceanographic conditions. I will also assess the connections between local shifts in spawn timing and temporal trends in herring stocklet biomass.

March 7, 14:00 (S2-11801)

On linking variability in early growth to habitat occupancy and mortality later in life: Anchovy in the Bay of Biscay

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Growth is a key parameter of population dynamics, linking vital rates with behaviour and spatial occupation. We studied individual fish growth trajectories in the anchovy of the Bay of Biscay. We measured annual growth increments in the otolith of individual fishes collected on the annual fisheries survey Pelgas from 2001 to 2015. The population separates into larger fish at age who occupy off-shore habitats and suffer higher mortality while smaller fish at age have a more coastal distribution and experience lower mortality. Fish length at first winter (growth at age-0) deterrmines life-time growth trajectories. Differences among individuals in growth at age-0 can be due to their birth date, as individuals spawned earlier in the season could grow over a longer period than individuals spawned later. Another hypothesis concerns variation in growth rate depending on experienced environmental conditions. To attempt separate these effects, we used otolith-derived juvenile growth rates and satellite-derived hydrological indices over the year. We also back-calculated birth dates from adult otolith analysis. Results show how spatial distribution and growth are intrinsically linked, which implies modelling the population with individual-based and physiological approaches to fully grasp its spatial dynamics.

March 7, 14:20 (S2-11764)

Use of otolith microstructure analyses to study the relation between larval hatching time, growth and survival in Norwegian spring spawning herring

Aril **Slotte**[1,2], Åse Husebø[1], Erling Kåre Stenevik[1,2], Frode Vikebø[1,2], Arild Folkvord[1,2,3], Petter Fossum[1] and Henrik Mosegaard[4] and Richard Nash[1,2]

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Sequential sampling within a population at different life stages may provide information on selective mortality patterns. Daily otolith increment widths at selected distances from the core were compared between larvae and 0-group juveniles within year classes, with the objective to test if survival in Norwegian spring spawning herring (*Clupea harengus* L.) is related to larval growth. In general the daily otolith growth during the first two-three months after hatching was significantly higher in the larvae than in the surviving population of 0-group. Spatial analyses demonstrated that the slowest growing larvae, having most in common with the growth observed in 0-group, were the ones originating from early hatching, found close to the coast and far to the north in mid May. Model simulations indicate that this near shore larval drift in general is associated with early hatching and colder ambient temperatures. The results suggest that a selection for the earliest hatched and subsequently slowest growing larvae take place during the larval phase in this herring stock.

Keywords: herring, larvae, otolith, growth, drift, survival

March 7, 14:40 (S2-11768)

Another critical period: Physiological limits determine recruitment success during the post-larval stage of a temperate clupeid (*Sprattus sprattus* L.)

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In most marine fish species recruitment is determined during the egg and larval stages when small changes in mortality have large effects on year-class strength. In Baltic sprat, however, previous studies showed that recruitment is determined in post-larval life-stages, which occur in coastal-near areas during summer and autumn. So far, research in the Baltic Sea concentrated on offshore areas where reproduction takes place and thus large knowledge gaps exist concerning the juvenile nurseries of sprat. Among the main factors influencing survival, predation and starvation, we found indications that starvation plays a dominant role. Laboratory studies with post-larval sprat revealed that food demand rapidly increases with size and temperature underlining the increasing risk of starvation. Thus, the timing of this food-demanding juvenile stage is probably of importance in regulating survival and subsequent year-class strength. To test this hypothesis, we performed a simulation of growth and food demand based on field otoliths and experimental data. The aim is to model the growth of seasonal cohorts and to detect those cohorts that experience best thermal conditions to fulfill maintenance and optimal growth at minimum food demand. Successful cohorts observed from otoliths of recruits represent those cohorts in the simulation that exhibit a low energy demand as juveniles. In contrast, earlier cohorts suffer from starvation due to high maintenance rations caused by large body size in combination with high temperature. The presented simulation approach enables us to study the seasonal plasticity of the sprat stock progeny thereby improving the understanding of recruitment variability.

March 7, 15:00 (S2-11509)

Do epigenetic effects of parental salinity conditions in herring influence subsequent offspring reproductive success?

Florian **Eggers**[1,2], Aril Slotte[3], Leif Andersson[4] and Arild Folkvord[1,3]

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Atlantic herring populations inhabit fully marine as well as nearly freshwater environments, but their reproductive success at these respective environments remains unclear. We conducted a factorial crossing experiment using twenty combinations of hybrid herring of marine (35 psu, Norwegian coast) and brackish water (6 psu, Baltic Sea) origin as parental fish. These had been reared their entire life at either 16 or 35 psu. The F2 offspring of all parental combinations were fertilized and incubated at 6, 16 and 35 psu. Fertilization rates after 24h were highest at 16 psu for all combinations. Successful fertilization also occurred at 6psu for all parental combinations, while males originating from 16 psu yielded relatively low fertilization at 35 psu. Hatching rates were comparable between 6 and 16 psu, but was lower at 35 psu. Combining fertilization and hatching rates indicated significantly higher reproductive success in 16 psu independent of parental environment. Survival rate after fertilization did not differ between 6 and 35 psu groups, irrespective of parental salinity. However, parental combinations including males from 16 psu had almost no reproductive success at 35 psu. This result suggests possible epigenetic effects of parental salinity conditions in herring on subsequent offspring fertilization and hatching success. The variable fitness as measured by fertilization and reproduction success is expected to have pronounced evolutionary consequences when occupying new habitats or when interbreeding between populations from differing habitats might occur.

March 7, 15:20 (S2-11748)

Combination of income- and capital-breeder type stocks of Japanese anchovy population

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Magnitudes of stock fluctuations vary among small pelagic fish species. The stock of Japanese anchovy has been known to fluctuate weakly rather than Japanese sardine as a whole population. When we look into the areal difference within the anchovy population, the magnitude of fluctuation is small in the southern Kuroshio stock (KR) but large in the northern Oyashio stock (OY). Spawning temperatures were calculated from the datasets of egg surveys during 1980 and 2015. The temperature in KR was found to have ranged from 15–28˚C without a peak, while in OY it was narrow ranged from 13–19˚C with a distinct peak of spawning activity at 15˚C. The difference in the range of spawning temperature between KR and OY corresponds to different reproductive characteristics between income- and capital-breeder types of stocks previously reported. This difference seems to be associated with the difference in the magnitude of population fluctuation in the stocks; large fluctuation in a capital-breeder type OY and small fluctuation in the income-breeder type KR. The population of Japanese anchovy as a whole can avoid stock collapse owing to the presence of stable KR, and can increase to high level with an explosive growth of OY. This seems to be like bet-hedging strategy of the anchovy population.

March 7, 16:00 (S2-11818)

How do Atlantic herring and Pacific herring compare in terms of reproductive investment and adult body growth?

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Both Pacific and Atlantic herring are composed of several stocks with characteristic life history traits. As for British Columbia, several stocks in Norwegian waters inhabit fjord-like systems, including the Balsfjord herring, which is known to be closely genetically related to the Pacific herring. This is believed to be due to earlier Arctic Ocean crossings by formerly Pacific members. These examples of similarities in history and local conditions form an excellent possibility to test further the earlier advocated concept of metapopulation structuring, by comparing presently reproductive investment (fecundity × egg weight) and related body growth characteristics of these two major players in the ecosystems in question. Differences in egg production among local populations were compared with similar data sets from the eastern Pacific. Complementary analyses on oceanic Atlantic components (spring and autumn spawners) were included to further understand regulation in reproductive investment. Our results show that the Norwegian components have size-specific difference in potential fecundity, but as spring spawners, all these local populations produced large oocytes. A latitudinal gradient was observed in reproductive investment along the Norwegian coast; northern, mid-latitude and southern populations. Both local Norwegian herring and the Pacific herring showed a higher relative fecundity compared to the Norwegian spring-spawning herring. Overall, both Atlantic local herring and eastern Pacific herring, when compared to Atlantic oceanic populations, are characterized by smaller body size, shorter life spans and higher relative fecundity.

March 7, 16:20 (S2-11810)

Designing a reproductive resilience index for small pelagic fish in the southern Humboldt Current Upwelling Ecosystem

Andres **Ospina-Alvarez**[1,2], Sebastián Vasquez[2], Cristian Salas[2], Sergio Núñez[2], Marco Arteaga[2] and Aquiles Sepulveda[2]

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Recent studies have demonstrated that current assessment practices based on spawning stock biomass to recruitment relationships do not capture important drivers of reproductive success. To understand spawner-recruit systems, we need to expand beyond traditional reproductive strategy concepts to include traits affecting reproductive success. Some of them are the spawning site selection, reproductive timing, larval behavior and dispersal and recruitment variability. The Humboldt Current Upwelling Ecosystem (HCUE) supports productive pelagic fisheries. The southern region of HCUE, i.e. central-southern Chile (34-40°S), sustains large pelagic fisheries that include the common sardine (*Strangomera bentincki*), anchoveta (*Engraulis ringens*) and jack mackerel (*Trachurus murphyi*). We studied biological traits affecting the reproductive success of these marine exploited fishes to improve our understanding of the causes conditioning temporal and spatial shifts in adult abundance. Our approach includes the use of data from acoustic surveys, egg production methods traditional stock assessments and biophysical models. We show how to deal with low-resolution or unavailable data on spatiotemporal reproductive behavior allowing us to consider spatio-temporal dynamics in spawning site selection, reproductive timing and egg production. We use biophysical models to unravel the effects of physical and environmental factors on larval transport, dispersal and reproductive success. The period studied include El Niño and La Niña events and their consequences in small pelagic fisheries. We found important differences in reproductive resilience between species linked to the dimension of effective used habitat. Our study would contribute to a better assessment of pelagic fish populations and stock productivity in the southern HCUE.

March 7, 16:40 (S2-11701)

Comparative early life trophodynamics and larval growth of Alborán Sea sardine environmentally distinct larval habitats (Bays of Málaga and Almería) (*Sardina pilchardus*) (W Mediterranean)

Jose-María **Quintanilla**, Raúl Laiz-Carrión, Alberto García, Luis F. Quintanilla, Dolores Cortés, Francisco Gómez-Jakobsen, Lidia Yebra, Soluna Salles and Jesús M. Mercado

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A combined study of environmental variables, daily growth, otolith biometry and stable isotope analysis (SIA) was undertaken to estimate the trophic influence on larval growth rates. Two main sardine (*Sardina pilchardus*) larval concentration sites (Bays of Malaga and Almeria in the northern Alboran Sea) were analyzed from the two places shape fairly contrasting environmental habitats for larval growth. Post-larval stages of sardine ranging from 10 to 21 mm standard length were sampled in both bays. Physical and biological data (including different phytoplankton and zooplankton size fractions as components of the planktonic food web) were collected for analyzing the early life trophodynamics of the two larval populations as well as determining the influence of the environment on growth variability. The larval growth models indicate differential growth strategies, where the cohorts from the Bay of Almeria show faster growth evidenced by greater body size and otolith radius with age.

Growth differences between larvae were analyzed by determining the C and N stable isotope enrichment of the larval cohorts in relation to the isotopic composition of the phyto- and zooplankton. The SIA of each larval cohort show significant differences. Whilst $\delta^{15}N$ signatures are significantly higher in the Malaga Bay larvae, $\delta^{13}C$ were significantly greater in Almería Bay larvae which impies different energetic sources on behalf of each larval cohort. Early life trophodynamics is discussed on the basis of a comparative approach analyzing ontogenic variations of the isotopic signatures with age. This work was supported by TROFOALBORAN (CTM2009-07776) and MOLDIALB (P11-RMN-7354) projects.

March 7, 17:00 (S2-11946)

Reproduction history of Peruvian anchovy and its relationship with environmental changes 1961 - 2015

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Information on gonadosomatic index (GSI), fat content (FC) and condition factor (K) from 1986 to 2015 is used to examine the reproductive history of the Peruvian anchovy (*Engraulis ringens*) from the Peruvian northern-central stock (03°33' to 15°59'S). Seasonal patterns and variability were analyzed and statistical filters were used to determine decadal changes or periodicity during the time series. An increasing trend of GSI and gonadal maturity in total and by size groups is shown since 1986. Interannual variability and changes in the behavior of the reproductive cycle for this stock is described. The literature describes the existence of two spawning periods of anchovy, one main winter-spring and one in summer (EINARSSON et al. 1966, JORDAN 1976, PEÑA et al. 1989). Here we show that larger adults (of 14 cm total length and larger) maintain a sustained reproductive activity throughout the year, while the increase of reproductive activity of smaller adults (12 to 14 cm) that mature and spawn for the first time is the one contributing to the spawning peaks. Seasonal variability and impacts on K from the strong 1982-83 and 1997-98 El Niño events were found. This study shows that FC and K do not show a trend and temporal changes are due only to seasonal patterns. Finally, variability in FC and K at a seasonal and annual scale are inversely related to variation in the gonadosomatic index (GSI). The hypothesis that variations of the reproductive indexes as well as fecundity estimations are part of a reproductive strategy of anchovy in front of environmental changes is discussed or it is part of a process of adaptation.

March 7, 17:20 (S2-11767)

Drivers of recruitment dynamics in northeast Atlantic pelagic fish stocks

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Recruitment is determined by various internal and external drivers. Size of a stock as well as its age, size and trait composition, cohort and trophic interactions, and environmental factors all influence recruitment processes. These drivers are potentially connected with each other, and are likely to vary in their relevance over time due to environmental changes or anthropogenic impacts. To improve our understanding of recruitment dynamics, it is therefore crucial to combine different approaches and methods to explore the importance of different internal and external drivers as well as potential temporal changes. We analysed the occurrence of density dependence in recruitment and growth in 21 commercially relevant small pelagic stocks of the northeastern Atlantic. In addition, we applied autocorrelation analysis to detect cannibalism/inter-cohort competition, and Bayesian switch-point models to investigate potential regime changes in stock-recruitment relationships. We further studied the correlation between recruitment residuals and relevant environmental indices. The results revealed low density dependence and few significant negative autocorrelations in recruitment residuals, suggesting that internal drivers of recruitment dynamics are of comparably little relevance in small pelagic stocks. Contrastingly, a high proportion of positive autocorrelations among year classes and our correlative analysis of large-scale environmental drivers indicate that external factors may be important as major determinants of recruitment variability for most pelagic stocks within northeastern Atlantic. This aligns with the literature and underlines the key role of specific external drivers for population dynamics of small pelagics and the importance of working towards incorporating environmental drivers in stock assessments and management plans.

March 7, 17:40 (S2-11899)

Site specific and inter-annual variation (2013-2016) in growth rates and jellyfish predation of larval Pacific Herring (*Clupea pallasii*) on British Columbia's (Canada) Central Coast

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Larval herring survival is expected to be a key determinant of recruitment success and year class strength in herring stocks. Feeding success, temperature driven growth rates, and predation represent three inter-related determinants of survival. First feeding success has been demonstrated to directly impact herring larvae through starvation mortality. Of particular importance in this regard is the temporal and spatial overlap of herring larvae with spring phytoplankton bloom dynamics (match-mismatch hypothesis). After first feeding, food availability and temperature determine growth rates and size dependent predation mortality. We used a four-year dataset from British Columbia to investigate larval growth and species-specific jellyfish predation in natal rearing areas. We observed that although spawn timing varied from year to year, this variation was less than that of spring bloom timing. The feeding conditions experienced by larvae were therefore expected to vary significantly among sites and years. In fact, larval growth at 38% of sites was <0.1mm per day, indicating unsuccessful first feeding and possibly site-specific recruitment failure. Furthermore, starvation could increase larval vulnerability to predation. Daily jellyfish predation was as high as 94%, indicating that jellyfish abundance (and species composition) can be a major determinant of mortality, and may therefore significantly the population dynamics of Pacific herring. Understanding the factors which influence the strength of a particular year class will allow us to better manage this ecologically and socio-economically important species in future years.

SESSION 2, DAY-3, March 8

External drivers of change in early life history, growth and recruitment processes of small pelagic fish

March 8, 10:40 (S2-11917)

Physiological modelling of the foraging and growth of early life stages of small pelagic fish: Fish don't eat temperature

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If one hopes to make robust projections of how climate change will impact on populations of small pelagic fish, it is critical to understand how temperature and prey interact to constrain the survival and growth of early life stages. We compare temperature- and size-specific bioenergetic rates of larvae among species of small pelagic fish to estimate differences in prey requirements/ starvation potential (metabolic rates) and thermal windows (growth/ feeding rates). In terms of modelling the direct effect of temperature, Oxygen and Capacity Limited Thermal Tolerance (OCLTT) provides a framework to mechanistically understand optimal, sub-optimal and critical/ lethal thermal limits of species. Using Atlantic herring (*Clupea harengus*) as an example, we demonstrate how OCLTT can be incorporated into a model to produce more robust (mechanistic) projections of regional changes in growth and survival in response to climate-driven warming. In terms of modelling indirect effects, size spectrum theory is now often used to depict marine ecosystem trophodynamics. Using both European anchovy (*Engraulis encrasicolus*) and Atlantic herring, we demonstrate the sensitivity of growth and survival during the larval period to relatively modest changes in prey niche breadth and slope of the plankton size spectrum. Correctly formulating the mechanistic impacts of temperature and prey on growth and survival in models will, in many cases, require additional, basic research on the physiology of modelled species.

March 8, 11:00 (S2-11825)

Is fishing driving energy acquisition and allocation changes in the Norwegian Spring-Spawning herring?

Marion **Claireaux**[1], Katja Enberg[1], Mikko Heino[1,2], Christian Jørgensen[2,3] and Bruno Ernande[4]

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There is a strong body of evidence that fishing pressure is driving the decline in age at maturity for a wide range of exploited demersal species. However, similar changes in age at maturity have not been reported for heavily fished pelagic stocks such as Norwegian Spring-Spawning herring (*Clupea harengus*). If maturation age is not evolving as a result of fishing in this species, other life-history traits may be evolving in adaptation to fishing mortality. Indeed, preliminary analysis shows showing changes in the stock's growth and condition i.e. shorter length-at-age and heavier weight-at-length. Using the non-linear mixed effect models framework to fit energy allocation models, we estimate energy allocation parameters (e.g. energy acquisition rate, energy allocated to reproduction) for 70 cohorts of Norwegian Spring-Spawning herring to obtain a time series for each parameters. We then attempt to disentangle the contribution that environment and fishing have on the potential changes observed in the estimated parameters. Adjustments in energy acquisition and allocation in response to fishing can be the cause of the lack of change in age at maturity, and might have unexplored effects on other life-history traits. Our analysis has the potential to bring new knowledge about how fishing affects Norwegian Spring Spawning Herring and small pelagic species in general, and might bring new insights for management of these stocks.

March 8, 11:20 (S2-11832)

Variations in vertical distribution of anchoveta eggs under contrasting spawning habitat characteristics: An environmental or maternal effect?

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Specific density largely determines the depth of the eggs in the water column. However, it is seldom assessed whether this varies during the embryo development, along the spawning seasons or among localities. Similarly, whether changes in density occur from changes in the water column characteristics or if they result from maternal influence, remains poorly understood. This study compares the density of *Engraulis ringens* eggs, in three locations of contrasting environmental conditions along Chile: north upwelling zone (Iquique, 18°S), central upwelling zone (Talcahuano, 36°S) and northern Patagonia (Reloncaví fjord, 42°S), their changes during embryo development, and changes in egg vertical distribution during the spawning season. These results are analyzed along with data on biochemical components of the eggs (maternally inherited) that may affect their buoyancy (proteins, lipids and free aminoacids) either obtained during the same cruises or from previous studies in the same locations. Results show that in the northern zone, where there is a sharp thermocline and a shallow oxygen minimum layer, eggs occur near surface. Contrastingly, in the fjord region, where fresh water input is strong and seawater is much colder, eggs stay deeper. Changes in the eggs vertical distributions and in water column characteristics occurred in all regions during the spawning season, suggesting a major role of the environment determining the depth of the eggs. However, differences among locations in egg specific density and in their biochemical components along the season also suggest a maternal influence that might modify the offspring chances of survival under changing environmental conditions.

March 8, 11:40 (S2-11880)

Observed pattern of diel vertical migration of Pacific mackerel larvae and its implication for spatial distribution off the Korean Peninsula

Hwahyun **Lee**[1], Sukyung Kang[2], Kyungmi Jung[2], Jung-Jin Kim[2], Dongwha Sohn[3] and Suam Kim[1]

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Measurement on specific gravity of Pacific mackerel *Scomber japonicus* larvae was carried out using density-gradient water column (DGC) (Martin In. Co. LTD) in the spring of 2014 and 2015. Larvae hatched in rearing tank from artificially fertilized eggs were fed rotifer 3 or 4 times a day. Even though specific gravity measurements revealed that larval specific gravity seemed to be much higher than the density of surrounding waters in spawning areas off the Korean Peninsula, a day-and-night difference in specific gravity was obvious for 4- to 9-day old larvae: the specific gravity observed in DGC showed the highest in the evening while it was lowest at dawn. Based on diel pattern of specific gravity, the diel vertical migration as well as spatial distribution that is the crucial component for determining recruitment variability of mackerel larvae could be modeled.

March 8, 12:00 (S2-11931)

Distribution of anchovy and sardine eggs and larvae in the Humboldt Current System of Peru from 1960-2014: Implications for fish abundance and reproduction

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Examination of the relationship between anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax sagax*) egg and larval abundance with physical and abiotic features of the environmental in the Humboldt Current System off Peru using nonparametric regression (Generalized Additive Models) suggest major differences between these two species in their spawning characteristics. The egg and larval distribution of both species reflect different distributions of spawning adults and also reflect differences in transport and oceanic conditions in spawning areas. Anchovy eggs and larvae are strongly associated with cooler waters, the coastal shelf, the two major spawning periods in winter and summer and are densest in the central shelf region of Peru, while sardine eggs and larvae are more evenly distributed along the coast, tend to stronger winter and summer spawning, are strongly associated with warmer and mixed waters, and are farther offshore (especially larvae) than anchovy, Comparison of long-term abundance patterns of anchovy eggs and larvae demonstrate that while egg and larval abundance are not good proxies for adult abundance or recruitment prediction, changes in the larval to egg ratio over time may reflects early recruitment success and may give insight into what conditions might lead to successful spawning.

March 8, 12:20 (S2-11721)

Development and nature of widespread and long-lasting *Ichthyophonus hoferi* outbreak in Icelandic summer-spawning herring

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A widespread *Ichthyophonus hoferi* outbreak occurred in the Icelandic summer-spawning herring stock during the years 2008 to 2014. The spatial and temporal variation in prevalence of heart lesions and the seasonal development of the infection in the stock were explored with an inspection of hearts to determine if fish were infected, as well as to categorize the heart lesions development stage. The sample prevalence of heart lesions in the fishable stock peaked at 43% in 2008/2009. The year classes from 2004-2006 had generally the highest prevalence, which varied from ~45-50% in 2008 to ~32-35% in 2014. New infection was apparently occurring in the autumns 2008, 2009, and 2010 while not in the autumns thereafter. This finding in addition to observed drop in the prevalence of the heart lesions in the winter 2011 but relatively stable and high prevalence thereafter, strongly suggest a little or insignificant mortality in the stock because of the infection since 2011. Furthermore, estimated total natural mortality of the different year classes from acoustical survey abundance estimates from 1992-2016 was not different before and during the outbreak. We conclude that the widespread *Ichthyophonus* outbreak in the stock lasting over six years caused only a minor additional mortality in the stock during the first three years and thereby much less mortality than anticipated from the literature.

March 8, 14:00 (S2-11811)

A space oddity: The case of the anchoveta (*Engraulis ringens*) in southern Humboldt Current system

Sebastián **Vásquez**[1], Cristian Salas[1,2], Andrés Ospina-Alvarez[3], Sergio Núñez[1], Marcos Arteaga[1] and Aquiles Sepúlveda[1]

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One of the main challenges in the management of small pelagic fishery is the understanding of recruitment dynamics under a changing climate. This is especially important for the anchoveta fishery in central-southern Chile (southern limit of its global distribution) which is highly dependent on the strength of year class. However, the drivers that modulate the reproductive success and the recruitment spatial patterns of the anchoveta are still unknown. Biophysical models allow us to explore the effects of biological and physical factors in the survival of early stages of development including those associated with parental stock, the larval behavior and abiotic conditions. In this study, the understanding of the recruitment processes of anchoveta is addressed through the application of a realistic spatial-explicit individual based model (IBM) from 1994 to 2014. The IBM was initialized with information from ichthyoplanctonic surveys and biological monitoring of spawning stock. The effect of spawner's distribution, timing of spawning, larval behavior and oceanographic conditions variability on the connectivity patterns, growth, dispersal scale and juvenile recruitment (20 millimeters in length) was analyzed from an interannual perspective. The results revealed that the spatial paths of larvae differed considerably year after year suggesting offshore advection as a main driver of survival. During El Niño events, the circulation pattern changed dramatically, leading to the formation of nursery areas not considered so far in the spatial structure of this specie. Finally, it is demonstrated that the IBM simulations are coherent with existing recruitment proxies and therefore open new possibilities for fisheries management.

March 8, 14:20 (S2-11776)

Spatial dynamics of juvenile anchovy in the Bay of Biscay

Guillermo **Boyra**[1], Marian Peña[2], Unai Cotano[1], Xabier Irigoien[1], Anna Rubio[1] and Enrique Nogueira[3]

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In autumn 2009, the implementation of two successive acoustic surveys targeting juvenile anchovy (*Engraulis encrasicolus*) in the Bay of Biscay allowed us to monitor the changes in the spatial distribution and aggregation patterns of juveniles of this species during 45 days under fairly stable meteorological conditions. Juvenile anchovy changed its biological condition and behavior in a different manner in two distinct areas. In the Spanish sector the juveniles migrated 20 n.mi. toward the coast, but they remained off the shelf and near the surface during the whole surveyed period. As the advance towards the shelf break progressed, their area of distribution decreased, their density increased and the juveniles spread in fewer but heavier shoals. In the French sector the juveniles migrated also from slope waters toward the coast at similar velocity, but they crossed the shelf break into the continental shelf, where they increased significantly their mean depth until gradually adopting the typical nyctemeral migrations of adult anchovy. The mean length of the juveniles that adopted the nyctemeral migrations was significantly higher than that of the juveniles remaining at the surface, suggesting that body size is relevant to accomplish this change. Besides, the stronger temperature gradients between shelf and oceanic waters in the Spanish sector, favored by a narrow shelf, may have acted as a barrier influencing the distinct observed spatial patterns in the two areas.

March 8, 14:40 (S2-11782)

Climate change scenario experiments predict a future reduction in small pelagic fish recruitment in the Humboldt Current System

Timothée **Brochier**[1], Vincent Echevin[2], Jorge Tam[3], Alexis Chaigneau[4], Katerina Goubanova[5] and Arnaud Bertrand[6]

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The Humboldt Current System (HCS) sustains the world′s largest small pelagic fishery. While a cooling of this system has been observed during recent decades, there is debate about the potential impacts of rising atmospheric CO2 con- centrations on upwelling dynamics and productivity. Recent studies suggest that under increased atmospheric CO2 scenarios the oceanic stratification may strongly increase and upwelling-favorable winds may remain nearly constant off Peru and increase off Chile. Here we investigate the impact of such climatic conditions on egg and larval dispersal phases, a key stage of small pelagic fish reproduction. We used larval retention rate in a predefined nursery area to provide a proxy for the recruitment level. Numerical experiments are based on hydrodynamics downscaled to the HCS from global simulations forced by pre-industrial (PI), 2 9 CO2 and 4 9 CO2 scenarios. A biogeochemical model is applied to the PI and 4 9 CO2 scenarios to define a time-variable nursery area where larval survival is optimum. We test two distinct values of the oxycline depth that limits larval vertical distribution: One corresponding to the present-day situation and the other corresponding to a shallower oxycline potentially produced by climate change. It appeared that larval retention over the continental shelf increases with enhanced stratification due to regional warm- ing. However, this increase in retention is largely compensated for by a decrease of the nursery area and the shoaling of the oxycline. The underlying dynamics are explained by a combination of stratification effects and mesoscale activ- ity changes. Our results therefore show that future climate change may significantly reduce fish capacity in the HCS with strong ecological, economic and social consequences.

March 8, 15:00 (S2-11817) MOVED to POSTER

Modelling the effect of environmental and anthropogenic factors on the abundance of early life-history stages of the European sardine in the Guadalquivir estuary

Enrique González-Ortegón[1], Marcos Llope[1,2], Francisco **Baldó**[1], Ignacio Sobrino[1], Carlos Fernández-Delgado[3], Pilar Drake[4] and César Vilas[5]

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Estuarine coastal areas play an important role in the recruitment of some small pelagic fish populations mainly when stable salinity-gradients are present. Damming of these ecosystems results in major alterations in this natural hydrological regime. Therefore, changes in the marine/freshwater balance can result in services loss, like the nursery habitat estuaries provide to small pelagic fish, such as sardines. Our previous work showed that the main important recruitment of sardine occurs in spring when this water balance is more variable. However, the drivers of sardine recruitment and particularly the interactive effects of environmental (temperature, salinity, turbidity and winds) and anthropogenic (freshwater discharges) factors are largely unknown. We modelled these effects on the abundance of sardine larvae and juveniles in the Guadalquivir estuary, the most southwestern one in the Atlantic Europe. Sardine early stages tend to occur at the most seaward and more saline sampling site in our study area. The best selected models included the freshwater flow and the wind regimen (northern-southern component) as main drivers explaining their abundance. Freshwater input –tightly controlled by a dam– had a negative short-term effect on the abundance of juvenile sardines above a critical threshold. On top of this, the wind-speed variability in the northern-southern direction showed a clear linear effect: with strong northerly winds enhancing the sardine abundance in the Guadalquivir estuary. These results contribute to the knowledge of the recruitment process of the European sardine and eventually to implementing an ecosystem approach to its fishery in the Gulf of Cadiz.

March 8, 15:20 (S2-11804)

Diet characterization and link between feeding success and recent growth of capelin (*Mallotus villosus*) during early ontogeny

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Survival of fish larvae is considered a key process that drives recruitment and determines the future biomass of a given fish stock. Successful feeding is a fundamental component that regulates growth and survival rate during early ontogeny. It has been previously demonstrated that fish larvae are selective feeders and that growth rate and survival can be hindered when preferred prey conditions are not met. Capelin (*Mallotus villosus*) stock from offshore Newfoundland and Labrador collapsed in the early 1990s and has remained at low levels since then. So far, larval capelin diet has only been described to prey size and broad taxonomical categories. This taxonomical resolution is not sufficient to reveal the link between abundance of the preferred prey group and early ontogenic dynamics. In this study we identified larval capelin prey at the lowest taxonomical level, comparing among two years where the capelin stock was considered collapsed (2002 and 2006) and a year where the stock started to increase in abundance (2014). First-feeding larvae fed primarily on copepodite and nauplii stages of *Pseudocalanus* sp. and *Temora longicornis*, followed by *Oithona similis* and nauplii of *Calanus* sp. Larger individuals shifted towards copepodite stages of *Pseudocalanus* sp., *Temora longicornis* and *Metridia longa*. *Pseudocalanus* sp. presented the highest contribution to diet in terms of carbon content across all larval size classes. We predict that variability in the availability of *Pseudocalanus* sp. may impact capelin recruitment through larval feeding success and growth.

March 8, 16:00 (S2-11914)

Exploring the microzooplankton-ichthyoplankton link: A combined field and modeling study of Atlantic herring (*Clupea harengus*) in the Irish Sea

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The importance of microzooplankton for the nutrition of early life stages of some fish species has been emphasized by several laboratory experiments. However this microzooplankton-ichthyoplankton link remains poorly resolved in field studies. Here we investigated the abundance, biomass and composition of micro- and small mesozooplankton (20-300µm) throughout the Irish Sea in November 2012 and 2013 in relation to the abundance, distribution and growth of larval Atlantic herring (*Clupea harengus*). In contrast to warmer months, microzooplankton biomass was highest in eastern areas, in the vicinity of the main spawning grounds of herring. The unicellular microzooplankton community was dominated by dinoflagellates (e.g. *Gymnodinium* spp., *Protoperidinium* spp., *Ceratium furca*), similarly to other temperate shelf seas in autumn/winter and. significant relationships between the abundance of larval herring and dinoflagellates (positive) and copepodites (negative) suggest complex grazing dynamics among lower trophic levels. Three *in-situ* zooplankton size fractions (<100, 100-200, 200-300 µm) were used as prey in a larval herring individual-based model. Simulations that omitted small zooplankton (<100 µm) under-predicted observed (biochemically-based) growth of 8- to 18 mm larvae. These results suggest that small planktonic organisms should be routinely surveyed to better understand factors affecting larval fish feeding, growth and survival.

March 8, 16:20 (S2-11806)

Mechanisms underlying bottom-up controls of small pelagics in the Gulf of Lions through experimental studies

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A recent shift has been observed in the Gulf of Lions ecosystem with considerable changes in biomass and fish mean weight of the three main small pelagic fish populations (anchovy, sardine and sprat). Surprisingly, these changes were not mediated through changes in recruitment, which remained high, nor related to overfishing, the exploitation rate being extremely low. A previous project refuted top-down control by tunas and marine mammals, as well as migration and epidemics as principal drivers of these changes. Rather, changes in size, condition and adult overmortality were suggested to derive from bottom-up control (i.e. changes in plankton composition) and possibly a change in life-history trade-offs, fish investing more into reproduction than earlier, despite being in lower condition. However, detailed mechanisms underlying the effect of plankton on fish life-history traits remained to be investigated. Therefore, we used an experimental approach to define the effects of food size, quantity and their interactions on fish foraging behavior, energy expenditure, growth and reproduction in wild sardines maintained in tanks. Preliminary results showed that under usual aquaculture food quantity (1.5% of fish biomass per day), sardines grew extremely fast and their condition and body lipid contents increased significantly, highlighting that the size changes observed in the wild did not result from adaptive modifications of growth. Differences in growth were also highlighted according to food treatment and catch-up growth was observed in sardines after food restriction. Further, depending on food size, sardines exhibited two different foraging behaviors, whose energetic costs are currently under study. Finally, the monitoring of reproduction of sardines under restricted *vs*. unlimited food will help understanding the link between increasing reproductive effort and survival rate.

March 8, 16:40 (S2-11953)

Modeling large-amplitude recruitment variability of small pelagic fish

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Abundances of small pelagic fish such as sardine and anchovy often changes dramatically at decadal timescale, which is generally caused by large-amplitude variation in the recruitment rate. While these fluctuations are often attributed to climatic forcing, processes linking these two levels are not necessarily resolved by field surveys. Marine ecosystem modeling has advanced considerably in recent years and some of the models almost fully cover physical processes and trophic levels from primary producer to carnivorous fish, or even to top predators and fishing fleets. Although these models have a good trophic resolution and technical capability of forecasting the responses of fish to climatic/environmental variability, most of them still do not have enough life-stage resolution to examine survival processes possibly occurring in relatively short terms. In the present study, we developed a simple food-web model for planktivorous and piscivorous fishes, focusing on mortality in early life stages. The model consider multiple larval/juvenile stages, and also covers the size range of factor 10^6. We focus on the environmental variability in the western North Pacific and the accompanied responses of sardine and anchovy, and test several growth and survival models during early life stages of these fishes. In the presentation, possible amplification processes from plankton to fish will also be discussed.

March 8, 17:00 (S2-11834)

Stepping forward in understanding recruitment variability of western Baltic herring

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Mean western Baltic Sea spring spawning herring (WBSSH) recruitment from 2000-2015 was ~50% lower compared to the 1990´s. However, evidence for potential reasons of this strong decline is missing. In order to test potential effects of prey availability on recruitment variability, biochemically derived larval growth rates, otolith derived hatch-date distributions, zooplankton data and a larval recruitment index were analyzed. Further, weight-at-age 1 (WAA 1) was compared to that of same-age conspecifics from another area (Kattegat). Length of investigated periods differed for each investigated parameter; every response variable was investigated at max. three sampling sites out of four. We found a significant correlation between WBSSH recruitment and the seasonal mean abundance of copepods for the period 2005 to 2013. Significant effects of prey availability on growth rates of small larvae (< 14 mm) were observed. Results from hatch date distributions suggest that juveniles, i.e., survived larvae, stem from periods were at least 10,000 copepodids m^{-3} were available on average. The total number of large larvae (20 mm; N20-index) per season from an important nursery area was twice as high in the 1990´s compared to 2000 onwards. Similarly, peak zooplankton (i.e., cladocerans and adult copepods) off-shore data were twice as high on average from 1991-1995 and 1999 compared to 2000-2012. WAA 1 was generally significantly lower compared to the Kattegat region and independent of recruitment strength. We conclude that prey availability significantly affects recruitment variability of WBSSH, and that juvenile condition of WBSSH is density-dependent.

March 8, 17:20 (S2-11929)

Juvenile Pacific Herring (*Clupea pallasi*) trophic linkages in the Strait of Georgia, British Columbia

Jennifer L. **Boldt**[1], Matthew Thompson[1], Chris Rooper[2], Chrys Neville[1], Doug Hay[3], Jake Schweigert[3], Rusty Sweeting[1] and Jaclyn Cleary[1]

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In British Columbia (BC), Canada, Pacific Herring (*Clupea pallasi*; herring) are an important species for First Nations, commercial fishers, and a variety of predators. As with other small pelagic fish populations, herring recruitment can vary substantially from year to year and new recruits can represent a large proportion of the adult population biomass, adding uncertainty to population estimates. There is a general understanding that the early life history period is important for determining fish survival and recruitment. Recruit abundance may be modulated by ecological and trophodynamic linkages between juvenile herring, their prey, predators, competitors, and the environment. Indices of juvenile herring abundance in the Strait of Georgia have varied annually, peaking in even years during 2004-2012, but with no overall trend during 1992-2015. Coincident to the lack of trend in abundance, juvenile herring condition has increased since 1997. We explored factors that may influence juvenile herring abundance and condition, such as spawning biomass and timing, prey availability, predators, competitors, and ocean temperatures. Investigating these linkages may improve our understanding of year class variability and knowledge about the role of herring in the food web.

Session 3
Oral Presentations

The role of small pelagic fish in food web dynamics between plankton and top predators

SESSION 3, DAY-1, March 9

The role of small pelagic fish in food web dynamics between plankton and top predators

March 9, 10:40 (S3-11865), Invited

To eat, to be eaten, and a lot of questions: Understanding the trophic ecology of small pelagic fish

Susana **Garrido**

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Small pelagic fish are typically abundant in the highly productive regions of the world's oceans where they are thought to control the variability of these ecosystems by exerting top-down control on their plankton prey and bottom-up control on their predators. Whereas some recent studies suggest that at least some of these ecosystems are more stable and diverse than initially thought, the importance of small pelagic fish in mediating energy transfer from plankton to higher trophic levels is indisputable. This talk will describe trophodynamically-mediated processes that influence small pelagic fish dynamics, from the indirect effect of spawner body condition on the quantity and quality of reproductive products, to the direct impact of food availability on larval survival. The plasticity and variability of small pelagic fish diets and feeding behaviours, morphological and behavioural adaptations of populations to prevailing environmental conditions, competition with co-occurring species, cannibalism and intraguild predation, and the simple difficulty of properly quantifying both their prey and their predators in the field make it difficult to assess the impact of environmental changes on the pelagic foodweb. However, studies using stable isotopic composition, laboratory experimentation and modelling are presently being carried out for several (and contrasting) ecosystems, including the Iberia/Canary, Benguela and California eastern boundary upwelling ecosystems and the Mediterranean Sea, which are advancing our knowledge of the relationship between environmental variability and dynamics of small pelagics, and these are briefly described and discussed.

March 9, 11:10 (S3-11716)

Ecological and functional role of key fish species from the pelagic community of the Mediterranean Sea

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Mediterranean marine ecosystems are fundamentally driven by their pelagic communities and small and medium-size pelagic fishes play crucial ecological roles. Although fluctuations of their populations have been mainly attributed to environmental variability and overfishing, there is still a lack of understanding on specific mechanisms that drive population changes, impairing the capability to predict future dynamics. Therefore, accurate scientific data at species and community level is needed at inter-annual and seasonal resolution. We used a multidisciplinary approach to advance on our knowledge about the ecological and functional role of several pelagic fish species in the western Mediterranean Sea, including clupeoids, horse mackerels and mackerels. We used energy density, stable isotope (nitrogen and carbon) and stomach content analyses to study seasonal variation in energy content in relation to their breeding strategies, feeding preferences and trophic role in the pelagic food-web. Results showed seasonal differences in energy density highly related with the spawning season and food availability, and differences in energy density and trophic niche between species. To integrate the new findings we developed two modelling approaches: a size-structured bioenergetics model based on dynamic energy budget theory to better understand how key species respond to environmental changes, and a qualitative model combining sign directed graphs with an analysis of Bayesian belief networks to test the role of potential pressures on main species. Overall, results provide pivotal information to assist the adaptive management of pelagic fish species in the region.

March 9, 11:30 (S3-11440)

Food web structure and small pelagic fish interactions in the Caspian Sea ecosystem, Iranian waters

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A mass-balance Ecopath model of coastal areas in the Caspian Sea has been constructed for a quantitative description of the trophic structure of the ecosystem. The model is used to estimate the important biological parameters and relationships among the different ecologically important groups. Twenty five species were used in the present analysis. The model is based on the data collected of Kilka fisheries, beach seining (Bony fish fisheries), and set Gillnet (Sturgeon Fisheries) and also dietary information. Total landings along the Iranian portion of southern Caspian coast reached 39647 t, including sturgeon (41 t), kilka (22873 t) and bony fishes (16733 t) in 2013. Two species of kilka (Common kilka and Anchovy) are important commercially in the Caspian Sea, together accounting in the past decade for > 60 % of the total catch, as well as being a crucial part of the food chain. The highest realized trophic level was obtained 4.04 for pike perch (*Sander lucioperca*). The calculated mean trophic level of small pelagic fishes such as *Clupeonella cultriventris* and *Clupeonella engrauliformis* was about 3 and small bentoplagic fishes such as *vimba vimba* and *Alburnus chalcoides* were 2.50 and 2.83 respectively, which suggests a stronger trophic link of this group with zooplankton. Mixd trophic level index (MTI) showed small pelagic fishes as prey, have crucial role in feeding of pelagic predators population such as invasion of the ctenophore *Mnemiopsis leidyi*, bream fish and benthic fish such as sturgeon. In general, niche overlap was greater in more species such as *Alburnus chalcoides*, *Rutilus rutilus*, *Clupeonella cultriventris*, *frisii kutum* and *M. leidyi* who consumed large amounts of plankton. In conclusion small pelagic fish exert a major control on the trophic dynamics of the Caspian Sea ecosystems and constitute midtrophic-level populations.

March 9, 11:50 (S3-11523)

Feeding conditions for small pelagic fish in the southern Baltic Sea based on the long-term analyses of the zooplankton abundance and community structure changes in response to various environmental stressors

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Mesozooplankton is a key element in marine food web. In the southern Baltic Sea conditions, it is extremely vulnerable to environmental forcing - observed changes in temperature and salinity influenced the zooplankton community structure significantly. Differences in abundance of key species at stations located in the southern Baltic Sea were analyzed and their response to the environmental factors was tested.

Presented data are the Polish contribution to the HELCOM COMBINE Programme. In most of the cases, samples were taken 5 times per year using the WP-2 net and the longest data series started in 1979.

Decomposition procedure was used to separate the key species time series into long-term trend, seasonal, and irregular components.

Profound changes in zooplankton community were recorded at the deep-water stations. This was mostly caused by a decrease in abundance of *Pseudocalanus* copepods. *Pseudocalanus* abundance correlates with salinity and, thus, positively responding to each of the inflows of more saline waters from the North Sea. Similar changes were not observed at shallow-water stations.

Long-term dynamics of the mesozooplankton community was discussed in the context of feeding conditions for small pelagic fish.

March 9, 12:10 (S3-11636)

Atlantic herring *Clupea harengus* within the coastal food web of shallow inshore waters

Paul **Kotterba**[1], Patrick Polte[1], Dorothee Moll[1,2], Lena von Nordheim[1,2], Cornelius Hammer[1], Daniel Oesterwind[1] and Myron A. Peck [2]

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Alike their Pacific counterparts, distinct subpopulations of Atlantic herring undergo intensive spawning migrations to coastal inshore waters. These areas provide appropriate demersal spawning substrate (e.g. littoral macrophytes) and favorable growth conditions for hatchlings and larvae. Although this particular herring spawning ecology results in an annual multi-month presence of the species' distinct life-stages in inshore waters, little is known on how herring and its offspring are actually niched within the resident food webs. While herring is commonly assumed to occupy identical food web positions as in the well-studied offshore areas, we hypothesized diverging patterns for inshore waters and exemplarily investigated a Baltic subpopulation of Atlantic herring and the different interactions that arise from the ephemeral coexistence of these herring and the resident inshore community. With a unique combination of field investigations, *in-situ* experiments and data series analyses, we examined the inshore feeding ecology of adult herring and the top-down control of herring eggs and larvae by resident predators. While adult herring stopped feeding during spawning, we observed an unexpected active preying on demersal macroinvertebrates and fishes during periods outside of the spawning season contradicting the generally accepted classification of herring as a strictly zooplanktivorous and pelagic species. Herring eggs are subject to an intense predation by stickleback and other resident predators, while predation on herring larvae was found to be negligible. Our results illustrate a strong connectivity between offshore and coastal systems and create new insights into the actual plasticity of herring ecology.

March 9, 14:00 (S3-11653)

Trophic interactions of Atlantic mackerel (*Scombrus Scomber*) and herring (*Clupea harengus*) on the Icelandic shelf – A study of diet using stable nitrogen and carbon isotopes

Cecilia E.K. **Kvaavik**[1,2,3], Guðmundur J. Óskarsson[1], Hildur Pétursdóttir[1], Jonathan Grabowski[4], Anna Kristín Daníelsdóttir[3] and Guðrún Marteinsdóttir[2]

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Warming of the world's oceans has caused many pelagic marine species to shift their distribution - especially in a pole wards direction. Pelagic fish populations can be very abundant and may have a great impact on the ecosystem. Extensive numbers of pelagic fish enter the Icelandic waters during summer to feed, it is estimated that ~1.5 million tonnes mackerel (*Scombrus Scomber*) and ~ 3 million tonnes herring (*Clupea harengus*) enter the Icelandic shelf each year during their summer feeding migration, indicating that these stocks can exert significant top-down pressures on the food web. The mackerel are opportunistic feeders and feed on a variety of zooplankton and small fish, whilst herring are mainly filter feeders of zooplankton. Research into the diets of these two species suggests that the main zooplankton prey species in Icelandic waters are copepods (primarily *Calanus finmarchicus*), euphausiids, pteropods, amphipods and appendicularia. Mackerel also include fish prey such as larval sandeel (*Ammodytes* spp.), herring and capelin (*Mallotus villosus*).

This study focuses on the differences between the diets of these two key pelagic species as well as the trophic links between them and their lower trophic level prey. This is done by analysing the stable isotope signatures (δ13C and δ15N) which reflect biologically assimilated nutrients from the diet over a longer time period. Results of the isotope analysis coupled with stomach content data will be presented, with focus on the diet composition and estimate of the dietary impact of these two pelagic species on lower tropic level species.

March 9, 14:20 (S3-11854)

Overfishing of planktivorous fishes may result in smaller plankton and less efficient energy flow to higher trophic levels

Tore **Johannessen**

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Measurements obtained in a spring blooming ecosystem show that after the spring bloom the main source of nutrients for algal growth stems from recycling. Furthermore, primary productivity (PP) is maximum in summer when phytoplankton biomass is low and nutrients hardly detectable as measured at macroscales. This implies high grazing rates, rapid cycling of ample nutrients at microscales, and the dominance of edible phytoplankton over non-grazed species. To account for this phenomenon, a mechanism for the positive coexistence of herbivores and their preferred algal prey has been proposed, which also involves bacteria, heterotrophic nanoflagellates (HNF), and viruses taking part in the cycling of nutrients. Based on this predator-model, primary productivity (PP) stands out as an important structuring variable in marine planktonic food webs, by larger plankton being favoured at lower levels of PP and smaller plankton at higher levels of PP. Fish feeding on plankton will contribute to reduced nutrients in the euphotic layer due to their relatively large faecal pellets sinking rapidly to deeper water, whereas the small faecal pellets from zooplankton are mainly recycled in the plankton community. Overfishing of planktivorous fishes will thus contribute to more nutrients in the euphotic layer and increased PP, which in turn will favour smaller plankton and thereby less efficient energy flow to higher trophic layer. In contrast, as many of the planktivorous fishes feed on larger plankton, classical antagonistic predator-prey models predict that large stocks of planktivores will result in reduced abundances of their prey, i.e. larger plankton.

March 9, 14:40 (S3-11803)

Pre-wintering adult capelin (*Mallotus villosus*) feeding dynamics off the northeast coast of Newfoundland and Labrador

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Capelin (*Mallotus villosus*) is the main forage fish in the Northwest Atlantic that sustain top predators such as Greenland halibut, northern gannet, minke whale, and harp seal. The capelin stock inhabiting the Newfoundland and Labrador shelf ecosystem collapsed during the early 1990s and has not yet recovered to pre-collapse levels. Recent studies have suggested that bottom-up control is preventing recovery of the stock. So far, the hypothesis of bottom-up control is mostly based on capelin diet information collected during spring. However, autumn also constitutes a crucial period where feeding supports overwintering and fuels gonadal development during the following season. In this research, we describe feeding of Newfoundland capelin during autumn over a 5-year time series (2008-2012) where capelin abundance has shown an increasing trend. Latitude was the main factor explaining variability in diet composition of capelin. Euphausiids dominated the diet in the south of the distribution range, while the proportion of copepods and hyperiids increased over a south to north gradient. An ontogenic shift in diet composition was observed with higher contribution of hyperiid amphipods and euphausiids in medium and large sized capelin. The contribution of copepods was always high and independent of size. Based on results obtained in this study and in previous work carried out before and after the collapse, we conclude that the Newfoundland capelin stock primarily relies on copepods both in spring and autumn. This contrasts with some of the other capelin stocks of the North Atlantic that are known to depend on euphausiids.

March 9, 15:00 (S3-11713)

A potential role of small pelagic fishes in combating dynamic deoxygenation occurring within intensified upwelling circulations

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Ocean deoxygenation appears to be a worsening global problem as climate change proceeds. Major deoxigenation is known to commonly take place in ocean regions that feature particularly intense coastal upwelling circulations. Concerns arise in view of an emerging consensus that coastal upwelling systems around the world may, more likely than not, continue to further intensify as "man-made" climate change proceeds. Some anecdotal and/or circumstantial evidence as well as the existence of plausible mechanisms offer at least speculative support for a significant role of strongly swimming small pelagic fish that possess particularly fine gillraker meshes (e.g., sardines) in countering deoxygenation within intensified coastal upwelling circulations.

A mechanistic scheme is presented that may draw several prominent examples (Somalia, Namibia, and Oregon) into a common comparative context. The strength of horizontal surface flow divergence that drives the upwelling circulation, the pattern of horizontal flow vorticity, and the potentially manageable relative abundance of the local small pelagic fish species appear in this scheme as possible controlling variables. To the extent that ocean deoxygenation may be considered a particularly urgent and growing problem, this may argue for expanded resources for scientific research on these mechanisms and species-specific effects beyond those that could be based merely on the perceived fishery or *in situ* trophic web value of the small pelagic fish populations involved.

March 9, 15:20 (S3-11808)

The paradox of fish abundance in the Northern Humboldt Current system: Why is it so productive?

Arnaud **Bertrand**[1], Alexis Chaigneau[2], Hervé Demarcq[1], Dimitri Gutiérrez[3], Monique Messié[4], Ricardo Oliveros-Ramos[5], Gary Vargas[3,6] and Francisco P. Chavez[4]

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The Northern Humboldt Current system (NHCS) off Peru produces more fish per unit area than any other marine ecosystem. In 1969, J.H. Ryther estimated that, to account for the fish productivity in eastern boundary upwelling systems (EBUS), and in particular Peru, you required a short food chain (1.5 trophic levels) from phytoplankton to fish. In addition, Ryther suggested that in EBUS there was an ecological transfer efficiency of 20% between trophic levels but that "it is possible that the actual values are considerably lower". Recent estimates of trophic levels and transfer efficiencies create a dilemma to explain the enormous fish productivity. Indeed, a low transfer efficiency (5%) has been estimated for other EBUS and there are likely 2.5 trophic levels from phytoplankton to anchovy. How then can the NHCS, with average primary productivity levels, produce so much fish? Here we estimate a trophic transfer efficiency of ca. 15% for Peru, which is less than Ryther's estimate but more than two times higher than in other EBUS. Two important attributes of the NHCS could explain these differences: i) Due to its proximity to the equator weaker winds produce the same level of upwelling as other EBUS with stronger winds but keeps macrozooplankton prey less dispersed; and ii) Habitat compression by a shallow oxygen minimum zone (OMZ), concentrates marine life within a fine shallow oxygenated layer. We show that fluctuations in anchovy biomass are intimately related to the OMZ depth and the macrozooplankton density within the surface layer.

March 9, 16:00 (S3-11870)

Ecosystem role of *Sprattus fuegensis* and impacts of its exploitation on the sustainability of other fishery resources

Sergio **Neira**[1,2,3], Hugo Arancibia[1], Mónica Barros[4], Leonardo Castro[1,2], Luis Cubillos[1,2], Edwin Niklitschek[5] and Rubén Alarcón[4]

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Sprattus fueguensis is a small pelagic fish sustaining an important fishery in inner waters of southern Chile and a likely prey for predatory fish, birds and mammals. Although the Chilean Fisheries and Aquaculture Law mandates the ecosystem approach to fisheries, *S. fuegensis* is still managed using a single-species approach. Thus there is ecological and management interest in the ecosystem role of this species and the likely impacts of its exploitation on the sustainability/conservation of fish stocks and top predators. We approached this issue by studying the main preys and predators of *S. fueguensis* in the study area, using gut contents and isotopes from samples obtained from 2011 to 2014. We also assessed the ecosystem impacts derived of the exploitation of this species by performing time-dynamic food web simulations using Ecopath with Ecosim. *S. fuegensis* is an important plankton consumer with a trophic level slightly higher compared to other clupeids. *S. fuegensis* is also as prey for fishery resources that because their status require immediate recovery actions such hoki, southern hake and kingklip. Besides, *S. fuegensis* sustains the most of the pelagic landings in the study area, being an important source of income and jobs for the artisanal sector. Food web simulations indicated that the biological reference points in the fishery of *S. fuegensis* ($F_{60\%}$) may not be precautionary. Therefore, special considerations should be taken regarding the sustainable exploitation of this species since overexploiting *S. fueguensis* may have important negative impacts for predatory fish, top predators and the food web.

March 9, 16:20 (S3-11775)

Long-term changes in prey items of larvae and juveniles of two clupeoid species in the Kuroshio-Oyashio transition region

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We investigated prey items of larvae and juveniles of two clupeoid species, sardine (*Sardinops melanostictus*) and anchovy (*Engraulis japonicus*), in the Kuroshio-Oyashio transition region during periods of 1970 to 1979 (sardine stock increase phase), 1980 to 1987 (high sardine stock phase), 1988 to 1991 (sardine recruitment failure phase) and 1992 to 1995 (anchovy stock increase phase). The larvae and juveniles were collected by surface ring net tows during April to June. Gut contents and prey organisms were identified to the lowest taxonomic level as possible, and their body length and width were measured. During 1970 to 1979 and 1992 to 1995, larvae and juveniles of sardine and anchovy fed on adult and copepodite stages of Calanoida and Poecilostmatoida copepods. During 1980 to1987, larvae and juveniles of sardine and anchovy larvae mainly fed on calanoida copepods such as *Paracalanus* spp. On the other hand, sardine juveniles consumed adult and copepodite stages of *Calanus* spp. but anchovy juveniles fed on Calanoida and Poecilostmatoida copepods and Thaliacea during 1988 to 1991. Furthermore, diversity of ingested prey items of larvae and juveniles of two clupeoid species during 1992 to 1995 was higher than that of the other periods. Our result shows that prey items of larvae and juveniles of sardine and anchovy was likely to be change with their stock or recruitment state.

March 9, 16:40 (S3-11915) CANCELLED

Relative influence of the Pacific Decadal Oscillation and coastal upwelling on productivity of plankton in the Oregon upwelling zone: 21 years of biweekly observations

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Since 1996, we have been studying seasonal and interannual variations in hydrography, nutrients and the abundance and species composition of phytoplankton and zooplankton in order to characterize the base of the pelagic food chain which supports small pelagic fish production in the Oregon upwelling zone. We have established that variations in wind-driven transport associated with the Pacific Decadal Oscillation seems to control copepod community structure in the Oregon upwelling zone – when northerly winds are strong, source waters that feed the northern California Current are from the north, thus cold-water boreal lipid-rich are transported to continental shelf waters off Oregon; when winds are more westerly or southerly, source waters are from the south and/or from offshore, leading to a warm-water subtropical, lipid-poor copepod. On the other hand, coastal upwelling is not correlated with abundance or species composition of plankton. Regardless, coastal upwelling must play a key role in local productivity because this is the process that leads to high primary and secondary production in the northern California Current (NCC). We will discuss linkages between basin-scale transport that deliver plankton the Oregon upwelling zone, and local-scale coastal upwelling which enhances productivity of the plankton that are transported to the NCC. The hope is that this work will produce a better understanding of the combined influence of basin-scale forcing and coastal upwelling on productivity of plankton (and ultimately small pelagic fish) in coastal upwelling zones.

March 9, 17:00 (S3-11886)

Effects of warming ocean conditions on feeding ecology of small pelagic fishes in coastal ecosystems

Mary Hunsicker[1], Ashley Hann[2], Richard **Brodeur**[1] and Todd Miller[3]

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Forage fish 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, and we may expect it to differ between warm and cold periods in the northeast Pacific Ocean. The recent unprecedented warming in the NCC provides a unique opportunity to better understand the connection between ocean conditions and forage fish feeding habits and the potential consequences for predators that depend on them for sustenance. Here we present findings from content analysis to examine food sources and trophic levels of multiple forage fishes (northern anchovy, sardine, mackerel, herring and smelts) off the Washington and Oregon coasts. Analyses were applied to fish and prey samples collected in May and June during years 2015 and 2016 (warm years) versus 2000, 2002, 2011, and 2012 (cold years). Results of the diet analysis indicate that fish feeding habits varied significantly between cold and warm periods. Euphausiids, decapods, and copepods were the main prey items of the fishes for most years, however gelatinous zooplankton were consumed in much higher quantities in warm years compared to cold years. This shift in prey availability was also seen in plankton and trawl surveys in recent years ans suggests that changing ocean conditions are likely to affect the type and quality of prey available to forage fish.

March 9, 17:20 (S3-11772)

Using trophically transmitted parasites to help understand the role and dynamics of small pelagic fish in the California Current

Kym C. **Jacobson**[1] and Rebecca E. Baldwin[2]

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Marine parasites with complex life cycles require multiple hosts and use predator prey interactions to complete their life cycles using to accomplish transmission. Small pelagic fish that serve key roles as forage in marine food webs also play key roles in transmitting marine parasites through food webs; from zooplankton to large predatory fishes, marine mammals and birds. Thus, trophically transmitted parasites in forage fish reflect the dynamics, spatial and temporal, of their predator prey interactions. Due to their longevity in fish hosts parasites extend the information provided by diet analysis. In this presentation we describe our results of different trophically transmitted parasite communities of Pacific sardine (*Sardinops sagax*) collected off Vancouver Island, British Columbia compared to those from samples collected off Oregon-Washington and California. Parasites of Northern anchovy (*Engraulis mordax)* also differed among sites off Washington and Southern California. Our results supported a reduced migration of Pacific sardine from Canada back to California, but also reinforced how parasites help document spatial and temporal dynamics in marine food webs. For example, a higher recovery in fish of parasites that use marine mammals as final hosts (e.g. Anisakid nematodes) in one region of the California Current versus other regions reflects the importance of both the forage fish and the marine mammal in the food web of that region. The recovery of parasites that use specific zooplankton taxa (i.e. a specific copepod or euphausiid genus) as intermediate hosts can also reflect the effects of ocean conditions on a food web.

March 9, 17:40 (S3-11862)

Feeding dynamics of Pacific herring (*Clupea pallasi*) in the northeastern Pacific coast of Canada

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There is a pressing demand for understanding of the pivotal role of forage fish in social-ecological coastal systems. Pacific herring ecosystem services are twofold: it is positioned functionally as a critical intermediate in costal food webs; and supports important traditional and commercial fisheries. Because of these strong ecological and human connections, significant declines of BC stocks have system-wide impacts requiring ecosystem-based analysis. The feeding ecology of the Pacific herring has received inadequate attention and currently ecosystem models recognize this species as almost exclusively an euphausiid consumer. Using multi-year (2004-2016) collections a detailed diet analysis was conducted and coupled with stable isotope measurements to elucidate region, season and size specific prey preferences of the Pacific herring. Over 1500 stomachs of herring ranging in size from 30 to 350 mm were analysed from the region between northern Haida Gwaii and Vancouver Island, covering intertidal to continental shelf habitats. Herring diets were highly flexible with a significant spatial and temporal variability. Overall however euphausiids were only a dominant diet source (~40%) of the 100-200 mm size group. In diets of smaller and larger herring, euphausiids accounted for <5 and <20% by weight, respectively, with copepods, amphipods, pteropods and larval fish dominating fish diets. Preliminary stable isotope data show an ontogenetic trophic level increase with a strong habitat portioning. New dietary data are compared to historical diet composition of Pacific herring in the northeastern Pacific and have already been implemented in the revised ecosystem model of the northern British Columbia.

SESSION 3, DAY-2, March 10

The role of small pelagic fish in food web dynamics between plankton and top predators

March 10, 09:00 (S3-11480)

Whale population recovery and forage fish in a Northeast Pacific ecosystem

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The aim of this study is to examine the potential effects of the recovery of depleted whale populations on Northeast Pacific forage fish, their predators and fisheries. Theoretical considerations suggest that such a recovery could reduce the biomasses of local forage fish stocks and predatory marine vertebrate populations and cause noticeable directional changes in the yields of some local fisheries. This study evaluated the plausibility of this hypothesis via ecosystem modelling in Ecopath with Ecosim (EwE). The study area included northern British Columbia (Canada) and the immediately adjacent part of Alaska (USA). The local pre-exploitation abundances of blue, fin, sei, humpback and sperm whales were estimated based on the total catches of each species recorded by whaling stations, the current local abundances of these species and whale intrinsic population growth rates observed locally and in similar ecosystems. The trophic effects of whale population recovery were then simulated using a mass-balance model of the local food web. The results of these simulations confirm that the potential recovery of some whales (particularly humpbacks) could have noticeable adverse effects on the biomasses of some forage fish (notably Pacific herring and saury) and, via indirect trophic interactions, on some piscivorous marine vertebrates (especially small odontocetes and seabirds). However, the effects of whale recovery on predator biomasses are sensitive to simulated variability in bottom-up forcing and to uncertainty in some ecosystem model parameters. These findings have practical implications for ecosystem-based management of forage fish in Northeast Pacific waters.

March 10, 09:20 (S3-11166)

The feeding ecology of mesopelagic fishes (*Lampanyctodes hectoris* and *Maurolicus walvisensis*) off the South African west coast: A comparative analysis using stable isotope and dietary data

Tamsyn **Tyler**[1], Astrid Jarre[1], Carl D. van der Lingen[1,2] and Ander de Lecea[3]

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The trophic ecology of two principal mesopelagic fishes off the west coast of South Africa, *Lampanyctodes hectoris* and *Maurolicus walvisensis*, sampled during the spring 2014 and autumn 2015, was examined using stable isotope and stomach content analyses. Isotopic signatures were analyzed in duplicate (i.e. lipid-extracted $\delta^{13}C$ and non-extracted $\delta^{15}N$) and prey composition was expressed using three dietary measures: frequency occurrence (%F), numerical abundance (%N), and dietary carbon (%C). The two species occupied different isotopic niches that were separated by their $\delta^{15}N$ values across a similar $\delta^{13}C$ range. The relationship between trophic position and standard length emphasized a structuring effect of size within the assemblage, with the larger species, *L. Hectoris* (SL 54.8±0.8mm; $\delta^{15}N$ 13.5±0.04‰), occupying a higher trophic position than *M. Walvisensis* (SL 37.7±0.6mm; $\delta^{15}N$ 12.5±0.11‰). Although copepods dominated the diet of *L. hectoris* in terms of numerical abundance (42%), macro-zooplankton was by far the most important dietary component, with euphausiids contributing 53% of dietary carbon. Conversely, copepods (i.e. *Calanus* sp.) were the most important component of the diet for *M. walvisensis* in terms of their occurrence (84%), numerical abundance (64%), and dietary carbon (67%). Though some dietary overlap exists between *L. hectoris* and *M. walvisensis*, the results suggest some resource partitioning within the assemblage - likely facilitated by differences in their alimentary morphology and respective foraging strategies. Nevertheless, sampling over a larger area of the southern Benguela and multiple years would be needed for a more comprehensive understanding of the trophic ecology of these two species.

March 10, 09:40 (S3-11879)

Small pelagics fisheries competition with seabirds: Review and application

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Competition between fisheries and marine wildlife for prey resources is a hot topic in conservation and the ecosystem approaches to fisheries (EAF). In some ecosystems, potential competition between marine birds and commercial fisheries for small planktivorous fish, such as sardines and anchovy, as well as euphausiid crustaceans, is of great concern, with detrimental interactions likely to grow in the future. Scientifically, this issue is complex, involving assessments of fisheries impacts on fish stocks in specific locations, as well as assessments of how changing local fish populations may affect seabird population parameters. Scaling issues and confounding by co-occurring climate variability and fisheries for large piscivorous fish, both of which may alter food webs through bottom-up or top down control mechanisms, makes this a vexing problem. In this presentation, we review the history of concerns, research, and management related to seabird-fisheries competition, approaches used to date to document competition (observations, experiments, and models), and provide guidelines for future research in support of the EAF for small pelagics. As the most conspicuous and readily studied upper trophic level consumers in marine ecosystems, seabirds provide a model system that may be applicable to other predators in marine ecosystems worldwide.

March 10, 10:00 (S3-11894)

Predator forage needs: Comparison and synthesis of bioenergetic and numerical response models

Julie A. **Thayer**, A.I. Szoboszlai and W.J. Sydeman

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Ecosystem-based management of lower trophic-level fisheries requires information on the needs of ecologically-dependent predators as well as multiple forage species. We developed a set of empirical models to test the hypothesis of general relationships between prey abundance and predator productivity across marine vertebrate classes. We also constructed predator bio-energetic consumption models of various prey (anchovy, sardine) for a broad suite of taxa. Numerical response models for piscivorous seabirds, fish, and mammals in the California Current Ecosystem (CCE) revealed a Type II relationship with thresholds ranging from 25-33% of the maximum long-term abundance (B_{max}) of schooling midwater forage nekton. This suggests the previously proposed global rule of "one-third for the birds" (Cury *et al.* 2011; Science 334:1703) applies to other marine vertebrates. Predators in the CCE showed similar non-linear responses to prey depletion regardless of prey type, predator class, or latitudinal region of the system. It has been suggested that pelagic fish thresholds needed to sustain predator production may be orders of magnitude higher than metabolic energy demands of predator populations. This is likely related to forage fish schooling behaviors and patchy distribution, in that the amount of forage needed in the water is larger than the actual amount consumed by predators. We synthesized results from threshold models (species-limited due to substantial data requirements) with broader taxonomic results of bioenergetic models. Such information can be utilized in establishing harvest control rules and also in stock assessment exercises to more realistically represent natural mortality.

March 10, 10:20 (S3-11797)

Understanding pelagic seabird 3D environment from multidisciplinary oceanographic cruises

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Seabirds move through the seascape searching for prey that varies spatially across different water masses/regions and vertically through the water column. Therefore, prey configuration and oceanographic processes could shape the three dimensional habitats of pelagic species. Multidisciplinary oceanographic cruises can provide information on seabird distribution and abundance, as well as the 3D configuration of prey fields and oceanographic environment. We applied this approach to the highly migratory sooty shearwaters (*Puffinus griseus)* that breeds in the southern Atlantic Ocean and visits the pelagic ecosystem of the Bay of Biscay (BoB) every autumn during their annual migratory journey, when the JUVENA oceanographic cruises monitor the pelagic ecosystem of the BoB. Taking advantage of this monitoring scheme, the spatial distribution of prey biomass was obtained based on hydroacoustics and pelagic trawls. In addition, horizontal fields of temperature, salinity, geostrophic velocities and mean thermocline depth were obtained based on hydrographic casts. Abundance spatial models were developed for the period 2013-2015 based on GAMs considering shearwater diving capabilities (i.e., prey and oceanographic environment were integrated from the sea surface up to 70 m depth). The main variables influencing shearwater distribution were the bathymetric gradient and biomass of small pelagic fishes, followed by the mixed layer depth. Spatial predictions identified higher areas of sooty shearwater abundance in the southwestern sector of the BoB. Integrative studies combining predator observations and pelagic prey can provide a comprehensive picture on the importance of refueling areas in determining migratory pathways with important implications in conservation strategies and climate change studies.

March 10, 11:00 (S3-11828)

Portuguese purse seine fishery spatio-temporal overlap with top predators

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The Portuguese purse seine fishery, with average annual catches of 60 000 tons, operates mainly in coastal areas and targets small pelagic fish. Incidental catches of seabirds and cetaceans have been observed for this fishery and they may also potentially compete for prey. For species with evidence of being directly affected by the fishery, the distribution of populations and fishing effort are key information pieces for spatial planning in the framework of ecosystem-based management. To explore the potential competition between the fishery and three top predators, we (i) analysed the spatial overlap between the distribution and abundance of the seabirds/cetaceans and the distribution of fishing effort and catch, (ii) determined their dietary overlap and (iii) estimated the annual consumption of seabirds/cetaceans and the fishery catch within the distributional range of one of their main prey species (*Sardina pilchardus*). Our analyses were performed on data gathered during 2011–2014. Overall values of consumption are of the same order of magnitude as mean annual purse seine landings for the studied area. Spatial and dietary overlap varied between 0.096 and 0.267, and 0.272 and 0.749, respectively, depending on the species considered. These estimates provide an indication of the potential for competition; however, they do not describe mechanisms by which competition with fisheries may alter reproductive success in these species. Our results identified areas where the impacts of intensive fisheries are likely to be greatest on the populations studied.

March 10, 11:20 (S3-11948)

Biology and ecology of killer whales (*Orcinus orca*) foraging around pelagic trawlers in the northeast Atlantic

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Dedicated studies on killer whale populations have been biased towards coastal locations, with logistical constraints limiting observations and data collection from pelagic waters. Recent observations from Irish pelagic fishing vessels highlighted an interesting interaction with large numbers of killer whales aggregating behind Atlantic mackerel (*Scomber scrombrus*) trawls during net hauling. This study aims to address key questions in relation to behaviour, population structure, diet and feeding strategies of this killer whale aggregation during the northeast Atlantic (NEA) mackerel migration. The project involves obtaining photo-identification data, skin biopsies, water (eDNA) and fish samples from pelagic trawlers. Previous observations suggest that the killer whales cease following the mackerel trawlers northwest of Ireland although the mackerel migration continues southwards. We will test the hypothesis that falling fat content/changes in lipid composition in mackerel is responsible for the abrupt cessation of killer whale movements with the migration. Photo-identification data will be compared with existing NEA killer whale catalogues to reveal individual movement patterns and geographical range. Molecular genetic, stable isotope and eDNA analyses will investigate whether this is a single population of killer whales specialising year-round on mackerel or if there are several populations in the NEA using mackerel as a seasonal food supply. This project will provide invaluable knowledge on the ecology of these killer whales which will ultimately aid in critically assessing their conservation status, contribute to the decision-making process with respect to applying an ecosystems approach to fisheries management and affording adequate protection under the EU Habitats Directive.

March 10, 11:40 (S3-11753)

Unclear associations between pelagic fish and jellyfish in four major marine ecosystems

Anders Frugård **Opdal**[1], Dag L. Aksnes[1], Richard Brodeur[2], Kristin Cieciel[3], Georgi Daskalov[4], Vesselina Mihneva[5], James J. Ruzicka[6], Hans M. Verheye[7,8] and David Checkley[9]

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During the last 10-15 years, a series of studies has suggested trends of increasing jellyfish (Cnidaria and Ctenophora) biomass in several major ecosystems worldwide. Some of these systems have also been experiencing declining, or non-recovering, historically dominant zooplanktivorous pelagic fish stocks. These observations have led to the hypotheses that jellyfish may replace pelagic fish through resource competition and/or through predation on early life stages of fish. In this study we test these hypotheses by using extended time-series of previously published data of jellyfish, pelagic fish and crustacean zooplankton from four major ecosystems within the period 1960 to 2014: the Bering Sea, the Black Sea, the Northern California Current and the Northern Benguela Current. We found no evidence of jellyfish biomass being related to the biomass of pelagic fish, or to a common crustacean zooplankton prey resource. Calculations of the energy requirements of pelagic fish and jellyfish stocks in the most recent years suggest that fish predation is 2-30 times higher than jellyfish predation, depending on ecosystem. However, compared with available historical data in the Bering Sea and Black Sea, it is also evident that jellyfish have increased their share in the common resource. We conclude that the available time-series data do not support the hypothesis that jellyfish are outcompeting, or have replaced, pelagic fish in any of the four investigated ecosystems. However, we cannot rule out the possibility that such effects have been masked by inadequate observations.

March 10, 12:00 (S3-11788)

Predation impact by juvenile salmon on early life stages of anchovy in the eastern North Pacific Ocean

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Although predation is thought to be the major limiting factor in fish recruitment, there have been few studies examining the effects of predators on prey populations. Juvenile Chinook and coho salmon are highly piscivorous (60-90% of their diets by weight) in their first summer at sea and are likely to be one of the most important fish predators on larval and juvenile fishes in coastal waters. The aim of this study was to examine the consumption of larval and juvenile Northern anchovy (*Engraulis mordax*) prey by Chinook and coho salmon in coastal regions of the Northern California Current (Oregon and Washington) by: 1) examining proportions of the anchovy prey in the diets of each predator by season and year and comparing these to available anchovy from contemporary trawl sampling, 2) comparing sizes of anchovy prey consumed relative to available sizes, and 3) estimating overall anchovy consumption by coho and Chinook salmon using bioenergetics modeling. Juvenile anchovies were the dominant prey consumed in late summer and fall over a seven year period (2005-2011), and in monthly sampling off the Columbia River in 2011 and 2012. Anchovy prey sizes ranged from >10 mm to <100 mm, and size-selectivity of anchovy prey varied by salmon species and study. Consumption rates of anchovy by Chinook and, to a lesser extent, coho salmon indicated that a substantial portion of the population was consumed over the years examined and suggest that predation may be a factor in regulating anchovy survival in some years.

Session 4
Oral Presentations

Comparison of methods for assessment of small pelagic fish populations

March 8, 10:40 (S4), Invited

Successful management of small pelagics within a large international region: The case for collaborative assessment work within the recently formed South Pacific Regional Fisheries Management Organization

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The area covered by the South Pacific Regional Fisheries Management Organization (SPRFMO) is some 1.9 million square kilometers. The organization was framed after the United Nations Fish Stocks Agreement in the implementation of UNCLOS. Among the diverse and important resources within the region, including jumbo squid, deepwater groundfish (e.g., orange roughy and toothfish), is the jack mackerel (Trachurus murphyi) resource. The jack mackerel stock was overfished and catches in the region exceeded 4 million tons per year in the mid 1990s. This highlighted the need for international management and the process of forming the SPRFMO Commission began in 2006. A side effect was that some countries chose to subsidize fishing activities in the region. This likely caused further stock declines with an all time low level of abundance in 2010. Fortunately, cooperative studies were conducted on biological issues and survey estimation methods such that stock assessments could be developed. These assessments account for alternative hypotheses on jack mackerel stock structure. Model development has progressed collaboratively among member scientists and the Commission has acknowledged and followed the scientific advice on catch limits throughout the range of the stock. The dynamics of the Scientific Committee activity and the Commission are reviewed. Also, the development of a rebuilding plan by member country scientists is discussed along with major outstanding questions being addressed through application of oceanographic analyses (such as defined suitable "jack mackerel habitat" to calibrate acoustic-trawl surveys).

March 8, 11:10 (S4-11891)

Assessment of Pacific herring (*Clupea pallasii*) populations in the northeast Pacific Ocean

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Despite extreme similarities in demographics and life history, model inputs and stock assessment model structures for Pacific herring populations across Alaska, United States, and British Columbia (BC), Canada, vary greatly. Choice of assessment model for Pacific herring stocks reflect available data and survey types, which for each population are highly dependent upon the topography, remoteness, and environmental conditions of each region, as well as the government funding. By examining similarities and differences among survey methods and assessment model structures currently used across Alaska and BC, regions can identify benefits and drawbacks of alternative methods, which can lead to improved assessment methods and performance of management procedures. Due to the similarity in demographics across populations, cooperation and information sharing across regions can aid in improving management with reduced costs.

March 8, 11:30 (S4-11504)

Incorporating time-varying fishery catchability in assessment models for Atlantic herring (*Clupea harengus*)

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Fishery catch-per-unit-effort (CPUE) is an important abundance index in assessments of many pelagic fish stocks, including Atlantic herring in the southern Gulf of St. Lawrence (GSL). Catchability - the proportion of a fish stock captured by a unit of fishing effort - is expected to vary over time for fishery-dependent data (e.g., fishery CPUE), which could cause bias in stock assessment estimates. Some sources of catchability variation can be controlled through effort standardization, but it is generally not possible to control other effects such as density-dependence or unmonitored spatial variation in effort. Assessments of GSL herring stocks that assumed constant fishery catchability indicate potential problems in model structure (i.e., severe residual and retrospective patterns). Here, we present assessment models that estimate and identify time-varying fishery catchability for all herring stocks in the GSL, where the extent and apparent causes of non-stationary catchability varied between stocks. Failure to account for this non-stationarity resulted in important bias in estimates of stock biomass and perceptions of stock status.

March 8, 11:50 (S4-11736)

Length-based assessment method for data-limited fisheries of small pelagic species

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Data for small pelagic fisheries can be limited in the amount of age-length data available for assessments. Often the data includes a limited set of age-length data and a larger data set of length data alone either from fisheries or from fisheries independent surveys. The method outlined here explores the range of von Bertalanfy growth parameters for the population using the limited current or historic age-length data available for the species. Next the method uses mixture distributions to current length data to generate multiple samples of cohort composition within the current fishery. Length based cohort compositions can be biased by greater presence of faster growing individuals in any given cohort. For this reason, the cohort samples generated in the previous step are fit using growth-type-group stock assessment approach to estimate current exploitation rates on the population.

March 8, 12:10 (S4-11815)

Insights into the recovery of Atlantic and Pacific herring following population collapse

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Many of the world's stocks of Pacific (*Clupea harengus*) and Atlantic (*Clupea pallasii*) herring collapsed during the past half-century. Collapse causes are often identified as overfishing and/or environmental changes, yet post-collapse trajectories are difficult to predict. However, recovery of biomass after collapse may be expected when a strong recruitment, or series of recruitments occur. The expected recovery time and influence of recruitment across herring stocks has not been analyzed. We examine various collapse scenarios on 50 herring biomass time series and describe the following biomass levels and their duration collapse. The effects of recruitment and other environmental covariates (e.g. SST and SSH anomalies) on post-collapse biomass are compared using generalized linear mixed effects models (GLMMs). Collapse events defined by the largest 3-year declines precede trajectories that take 16 years on average to recover to pre-collapse levels. Significant positive post-collapse cross correlations between recruitment and biomass were shown from 16 of 33 recruitment time series. Since half the recruitment series may not directly impact post-collapse biomass, we model the probability of biomass recovery with a logistic GLMM. Preliminary results support higher relative recruitment increases the odds of recovery, with evidence for the influence of SSH anomalies as well. One takeaway is that strong recruitment may not necessarily effect a strong recovery. The physical environment likely has a role in other processes such as natural mortality and growth during post-collapse. An improved understanding of post-collapse dynamics for a highly fluctuating forage fish such as herring helps to tailor management expectations for recovery.

March 8, 14:00 (S4-11820)

Evaluating the performance of production models with time-varying parameters for assessing small pelagic fish in dynamic ecosystems

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The dynamic nature of complex ecosystems provides serious challenges to stock assessment and management of small pelagic fish. The practical utility for fisheries management of most ecosystem models that mechanistically account for changes in productivity is limited by their extensive development time and data requirements. A potential alternative is single species surplus production models that estimate time-varying intrinsic growth (TVr). Such models may implicitly capture the effects of shifting anthropogenic and environmental drivers on a fish stock without having to explicitly model the exact underlying mechanisms. We tested the performance of production models with TVr by simulating shifting predation pressure on a pelagic fish stock. Linked age-specific, predator-prey dynamics between Atlantic menhaden, *Brevoortia tyrannus*, a small pelagic fish native to the Northwest Atlantic, and their predator Atlantic striped bass, *Morone saxatilis*, were simulated as a case study. Models with TVr produced more accurate and less variable estimates of exploitation rate than models with static intrinsic growth. Median relative errors in terminal exploitation rate were negatively biased for TVr and static models, but models with TVr were more accurate. Annual estimates of menhaden biomass were vastly improved with the incorporation of TVr. Application of the TVr approach to Atlantic menhaden indicated substantial changes in productivity over the last 50 years. By allowing productivity to change over time, models with TVr provide more accurate, dynamic, MSY-based reference points that can help fisheries managers make better, informed decisions about sustainable fishing quotas for small pelagics in dynamics ecosystems.

March 8, 14:20 (S4-11747)

Pelagic fish resources stocks assessment in southern part of the Gulf of Guinea: Benin Continental Shelf

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The global objectives of this campaign were to assess biomass and map the distribution of stocks of small coastal pelagics from Côte d'Ivoire, Ghana, Togo and Benin by hydroacoustic method and describe the hydrographic conditions in the area during the survey period.

During the survey we can note that fish density was too less in comparison with Nansen survey. It's true that both surveys was not doing in the same period. Data collected analysis show that *I. Africana* is the most important pelagic fish. *Ilisha africana* is not a target fish of artisanal fisheries; this species constitutes, for artisanal fishermen using gillnet named "sovi" a target of fishing. This species was catch by most of the fishermen using non-motorized boat [2].

The main pelagic species biomass of 3490 tons, are represented by Clupeidae (*Ilisha africana*) with a biomass of 310 tons. The other group consists of pelagic species other than *Ilisha africana* with a biomass of 3180 tons. Other pelagic fishes are the carangids, scombrids, sphyraenids. Some demersal fishes were cached during this survey. This very important study should help for fisheries management in our continental shelf and confirm need [1].

Keywords: Continental shelf, pelagic fish, hydroacoustic, *Ilisha africana*

March 8, 14:40 (S4-11750)

A new view on forage fish trends in relation to environmental conditions in the Gulf of Alaska

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Forage fish have an outsized trophic role in many marine ecosystems, supporting the transfer of energy from zooplankton to upper trophic fish, birds, and marine mammals. Despite this importance, robust estimates of forage fish abundance are often difficult to assess due to the lack of long-term surveys designed to capture forage fish. However, there are many marine predators that specialize in capturing forage fish. Just as survey nets have catchability biases, forage fish predators have selection biases. We hypothesized that integrating trends in relative abundance of forage fish across the diets of several species of groundfish and seabird predators may provide a robust estimate of forage fish abundance. Furthermore, relationships between the common trends found among multiple imperfect samplers of forage fish and broad-scale environmental processes may be easier to detect and interpret. We used time series of relative abundance of capelin (*Mallotus villosus)* and sand lance (*Ammodytes* spp.) from stomachs of arrowtooth flounder (*Atherestes stomias*), Pacific cod (*Gadus macrocehlalus*), pollock (*Gadus chalcogramma*), and Pacific halibut (*Hippoglossus stenolepsis*) collected during trawl surveys and from chick-provisioning black-legged kittiwakes (*Rissa tridactyla*) and tufted puffins (*Fratercula cirrhata*) to determine common trends using Dynamic Factor Analysis. These trends were then analyzed first using change point analyses to test for regime shifts and then using cross-correlations to test for lagged correlations with temperature and climate indices. Results indicate that capelin abundance appears to be responsive to temporal trends, including the recent warm water event, "the Blob", that occurred in the central Gulf of Alaska.

March 8, 15:00 (S4-11839)

Pacific sand lance – Assessment of benthic habitat, population structure, abundance, distribution and response to environmental drivers in the San Juan Archipelago

Matthew **Baker**[1], Gary Greene[2], Beth Matta[3], Adam Summers[1], Louise McGarry[4], Soren Huber[1], Erin Horkan[1], Jon McLean[1], Nancy Sealover[1], Marielle Beaulieu[1], Katie Cieri[1], Alyssa Tinnon[1], Olivia Graham[1], Emily Burke[1], Kailee Bynum[1], Thomas Pham[1], Alicia Highland[1], Jennifer Lopez[1], Nicolas Sisson[1], Charlie Heller[1], Annie Thomson[1], Mary Rood[1], Gary Winans[5], Phil Dionne[6] and Dayv Lowry[6]

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Sand lance and sand eels (*Ammodytes* spp.) are a critical component in northern latitude pelagic ecosystems. Throughout their range, there are significant knowledge gaps in the status of populations and stock structure. Pelagic fishes that shoal in the thousands, these species also rely on benthic substrates to conserve energy and escape predation. In Puget Sound and the San Juan Islands, there are more than 140 miles of spawning beaches and Pacific sand lance (PSL) have been documented in 80% of inland waters. Much less is known about benthic habitats. In the San Juan Islands, several dynamic sand wave fields that support populations of PSL are maintained by tidal currents and relic glacial deposits. Through an ongoing collaborative program at the Friday Harbor Laboratories, several sampling approaches have been applied, including acoustics surveys, beach seines, and benthic Van Veen grab samples to characterize pelagic and benthic habitats. This talk will summarize results of those surveys (2010-2016), as well as efforts to integrate multibeam surveys (detailed bathymetry and benthic habitat maps) and targeted sampling of sediments to estimate fish densities, predict distribution, and develop indices of abundance. Mark-recapture methods have also been applied and new methods to determine age structure developed. Analyses of diel, seasonal and interannual trends in these populations document shifts in relative abundance and condition in response to environmental variables, particularly in the context of North Pacific anomalous warming. These findings may have application to other areas that support this important family of small pelagic forage fish.

March 8, 15:20 (S4-11822) CANCELLED

The use of surveys in the assessment of small pelagic fish in the Bay of Biscay and Iberian Coast Ecoregion

Alexandra **Silva**[1], Lionel Pawlowski[2], Andres Uriarte[3], Fernando Ramos[4], Isabel Riveiro[5], Eduardo Soares[1], Erwan Duhamel[2] and Leire Ibaibarriaga[6]

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We present an overview of the assessment and management of four small pelagic fish stocks assessed by the International Council for the Exploration of the Sea (ICES) Working Group WGHANSA: Bay of Biscay Anchovy, Iberian sardine, Bay of Biscay sardine and Gulf of Cadiz anchovy. The cases illustrate "data-limited and "data-rich" approaches. All of the assessments integrate multiple types of data, namely catch data and data from several types of surveys (acoustic and Daily Egg Production Method surveys). They also illustrate different uses of survey data, such as the calculation of indicators to derive trends in abundance and harvest rates or the calibration of age- or stage-based assessment models. The goal is to highlight strengths, weaknesses and challenges in the assessments raised by the use of surveys and to discuss possible routes to improve their use and potential constraints. Specific situations that the use of multiple surveys has been an advantage or else increased uncertainty are highlighted. In most cases the use of multiple surveys increases the robustness of the assessment and avoids drastic/possibly wrong advice based on outliers.

March 8, 15:20 (S4-11849)

Estimating migration and mortality of adult Atlantic menhaden with data from a large-scale mark-recapture study

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Atlantic menhaden *Brevoortia tyrannus* is an economically and ecologically important small pelagic fish that is targeted by large-scale commercial reduction and bait fisheries. In the late 1960s, the U.S. Bureau of Commercial Fisheries conducted a large-scale mark-recapture study, in which they tagged over one million adult Atlantic menhaden along the U.S. Atlantic coast from Massachusetts to Florida. The individual ferromagnetic tags were passively recovered using magnets installed in reduction plants, which represented more than 95% of the harvest. Our goal was to develop and apply a novel mark-recapture model that could simultaneously estimate movement and fishing and natural mortality for Atlantic menhaden. We used a spatially explicit version of the Brownie dead recovery mark-recapture model, as modified by Hoenig et al. (1998), with additional allowance for tagging mortality and recovery probability at the reduction plants. Atlantic menhaden displayed seasonal movement patterns, however, the fraction of the population undertaking these migrations was substantially smaller than previously described. From June to September, Atlantic menhaden showed little movement, largely remaining within individual coastal areas. The estimated instantaneous natural mortality rate was approximately three times greater than previously reported. Instantaneous fishing mortality was spatially and temporally variable, with the highest values in the northernmost area (Massachusetts- Delaware) and the Carolinas. An explicit and quantitative understanding of Atlantic menhaden migration will guide interpretation of spatial patterns in future surveys. Additionally, a new and more accurate estimate of natural mortality will help inform management decisions. Similar approaches could also be applied to other pelagic forage fishes.

March 8, 16:00 (S4-11936)

New insights into small pelagics from industry self-sampling in Europe, West-Africa and the South Pacific

Martin A. **Pastoors**, Floor Quirijns and Inge van der Knaap

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Data collection from commercial fisheries is traditionally carried out by research institutes who will take regular samples of catches in the fish auctions or using scientific observers at sea. Although the information thus collected is appropriate for most stock assessment approaches, the level of sampling is often too low to get meaningful information on catch compositions and catch rates small temporal and spatial scale. The Pelagic Freezer-trawler Association (PFA) represents 18 freezer trawlers in five European countries and fishes for small pelagics in the Northeast Atlantic, off West Africa and in the South Pacific. The association initiated a self-sampling programme in 2015 to capitalize on the already ongoing sampling activities for commercial reasons and to provide a platform whereby fisheries knowledge and data can contribute to improved scientific understanding. Currently the programme is carried out on 8 vessels, generating haul by haul information on catches and environmental conditions, species compositions, mean weight of fish and length-frequency of a subset of hauls. During some fisheries there is data available on fat content, stomach fill and gonad weight. Applications of the self-sampling programme will be demonstrated relative to an improved understanding of horse mackerel (*Trachurus trachurus*) dynamics in European waters, jack mackerel (*Trachurus murphii*) in the southern Pacific and mackerel (*Scombrus scomber*) length compositions in European waters. The reliability of self-sampling information will also be discussed.

March 8, 16:20 (S4-11909)

Monitoring by direct surveys and integrated assessment of the Bay of Biscay anchovy (1989-2016) for the provision of management advice

Andrés **Uriarte**[1], Leire Ibaibarriaga[2], Guillermo Boyra[1], Erwan Duhamel[3], Lionel Pawlowski[3], Jacques Massé[4], María Santos[1] and Begoña Villamor[5]

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Assessment of Bay of Biscay anchovy started in 1987 with two series of parallel acoustic and egg production (DEPM) surveys carried out yearly in May. Over 30 years they have shown a general consistency (r^2= 0.54, n=22, p=0.0001) with occasional divergences. Based on data from these surveys and from the catches, the first integrated assessment was achieved in 1994 using Integrated Catch at age Analysis. Since 2004 the assessment has been based on a Bayesian two-stage biomass model aiming at better dealing with input errors and description of output uncertainties in probabilistic terms. Provision of advice until the fishery collapse in 2005 was based on scenarios concerning the unknown upcoming recruitment, either choosing a cautionary low level or accepting that any past recruitment could equally occur. This led to a good estimate of present and past stock status but to a poor provision of advice for the next year. Such situation triggered a change in the management calendar to July(y)-June(y+1) to reduce the uncertainty from the recruitment in the advice. The inclusion of a series of autumn acoustic surveys on juveniles in the assessment as an indicator of recruitment allowed improving the management advice. Nowadays the assessment provides the likelihood profile of the Biomass in January at the beginning of the management year (from January to December), incorporating the latest information on incoming recruitment. Results allow evaluating the impact of different catch options in probabilistic terms and are used to set the TAC according to an agreed management plan.

March 8, 16:40 (S4-11734)

Use of a potential habitat model to sample Pacific sardine abundance

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Estimating the abundances of small, migrating populations requires judicious use of sampling resources. In 2011, a model of the potential habitat of the northern stock of Pacific sardine off the West coast of the US was created to better guide the sampling effort during surveys using acoustic-trawl and daily egg-production methods. Using a 12-year data set of sardine presence and satellite-derived environmental data, the model indicated that sampling efforts could have been better allocated if only regions deemed statistically likely to include sardine were surveyed. Increased sampling effort in areas potentially including sardine reduces both sampling bias and variance. Since 2012, spring surveys for Pacific sardine have been designed with consideration of near real-time potential habitat maps, moving away from the traditional fixed-area approach. Due to the variable environment in the northeast Pacific during 2011-2016, the potential habitat model results motivated the sampling of considerable different survey areas, year-to-year. This strategy was particularly beneficial during 2015 and 2016, when warm waters and a reduced population resulted in an unusual northward shift in the stock's distribution. If the survey had not been guided by the results of the potential habitat model, then the residual population would not have been captured in sample space prescribed by traditional fixed-area designs, resulting in erroneous population abundances. When sampling patchily-distributed and highly mobile populations, habitat-based survey designs mitigate potential bias due to changes in environmentally-driven population distributions.

March 8, 17:00 (S4-11786)

Discerning connectivity and natal fidelity of Pacific herring (*Clupea pallasi*): Inferences on population structure from otolith chemistry

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Pacific herring, *Clupea pallasi*, are integral to coastal ecosystems of the northeast Pacific. These highly mobile fish undertake annual migrations between feeding and spawning grounds that link life stages, habitats, populations, communities, and ecosystems. The extent and direction of herring movements has a significant influence on food web dynamics and also affects the diversity and stability of herring populations. Exchanges of individuals among geographically separated groups can be a key driver of population persistence and resilience. Returns of spawning adults to sites of natal origin introduce complexity in spatial structure that could generate and sustain inter-specific variation in life history traits and response diversity. Identifying the direction and strength of linkages among groups can reveal key source populations and promote the development of population- and ecosystem-based management strategies that reflect ecologically relevant spatial scales. We sampled spawning herring in British Columbia and southeast Alaska in 2015 to evaluate the extent of mixing and natal fidelity among spawning locations using otolith elemental composition as intrinsic chemical "tags". We assessed the resolution of otolith elemental tags as discrete spatial markers at scales of 10s >1000 kms. Elemental composition was determined using laser ablation inductively coupled plasma mass spectrometry. Cohort-specific analyses were applied to assess the likelihood of fidelity to natal sites and broader, age-specific movement patterns. Otolith elemental signatures can provide insight into complex population structure to inform and enhance spatially-explicit approaches to conservation and management.

March 8, 17:40 (S4-11718) - CANCELLED

Assessment of the clupeids stock in Côte-d'Ivoire, using univariate SARIMA model

Toussaint Tapé **Joanny**

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The monitoring of small pelagic fish in Côte-d'Ivoire in the Gulf of Guinea takes into account only the landings of the industrial pelagic trawlers although the artisanal fleet activities is not negligible. Because the data is not complete, it is not useable with the schaefer dynamic global model to provide indications on the status of the stocks. But univariate seasonal-autoregressive-integrated-moving-average (SARIMA) model applied from a statistical process-control perspective to the monthly landings of clupeids of the period 2000-2010 could reveal large forecast errors, indicating variation of fishing effort and catches that may require management intervention.

Session 5
Oral Presentations

Future challenges for ecosystem-based management of highly variable fish populations

March 9, 10:40 (S5-11749), Invited

What are the challenges for ecosystem-based management of highly variable fish populations?

Verena **Trenkel**

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The challenges for monitoring, assessing and managing highly variable (in every sense) fish stocks are generally founded in this variability. They persist when moving to ecosystem-based management. At the same, in addition to single species management objectives, commonly related to maximum sustainable (economic) yield, a range of wider ecosystem management objectives needs to be considered. To match these objectives a new set of stock level reference points might need to be derived. These new reference points could have the role to ensure maximum sustainable (economic) ecosystem services (MSES), both fundamental services (prey, energy transport in space,..) and human demand driven services (catch, revenue). An important issue in this context is the potential trade-off between different services provided by small pelagic fish. Beyond reference points, other parts of the chain stretching from data collection to management advice require modification, or not, depending on the ecosystem. This presentation will briefly summarize single stock challenges and then explore the available knowledge and future research needs created when moving towards MSES management of small pelagic fish. Examples from European fisheries will be used as illustrations.

March 9, 11:10 (S5-11478)

Economic benefits from ecosystem-based forage fish management depends on fishing history

Timothy **Essington**[1], James Sanchirico[2] and Marissa Baskett[2]

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Forage fish are important as a target species in fisheries and as prey for fished piscivorous fishes, so balancing these competing benefits requires an ecosystem approach. While gains from the ecosystem approach appear intuitive, to date few have directly assessed the societal gains from adopting the ecosystem approach. Here we use a novel framework to understand when ecosystem based management is likely to lead to the largest gains. Specifically, we ask how optimal management decisions depend on the nature of the food web interactions, and how the economic value from fisheries management depends on precise knowledge of the true state of nature. To this end, we considered a series of nested economic-ecological models that differ in terms of complexity of predator-prey interactions of a common piscivore and forage fish system. We determined optimal management trajectories for each, finding that the pathway of exploitation rates that maximize economic value are highly dependent on the ecological interaction. Yet, we also find that in most cases, the cost of applying the incorrect harvest pathway i.e. assuming species are independent when in fact there is a predation interaction, were modest, generally reducing net present value by 0-10%. However, the costs of assuming the wrong interaction became very high when historical overfishing has heavily depleted the piscivore. We conclude that the application of ecosystem-based fisheries management does not require precise specification of species interactions but instead identifying conditions where the cost of being incorrect become large and developing harvest strategies that avoid those conditions.

March 9, 11:30 (S5-11481)

A reassessment of carrying capacity estimates for Northeast Pacific herring stocks

Szymon **Surma**[1], Tony J. Pitcher[1], R. Ian Perry[1,2] and Rajeev Kumar[1]

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Pacific herring (*Clupea pallasii*) is a large, long-lived and energy-rich forage fish, supporting numerous predators and fisheries in coastal waters from Korea to California. Given the poor current status of many Pacific herring stocks and recent calls for precautionary and ecosystem-based forage fish management, there is a clear need to investigate stock carrying capacities (K) or unfished spawning biomasses (B0). B0 estimates are used to calculate biomass threshold values regulating many herring fisheries. We applied Schaefer and Fox surplus production models to spawning biomass (SB) and adult catch time series to evaluate K (here = SB0) for nine large Pacific herring stocks from Alaska (AK), British Columbia (BC) and California (CA). Monte Carlo resampling from time series was used to generate 95% confidence intervals. Schaefer and Fox model SB0 estimates generally agreed well. Discrepancies between current and previously published Schaefer SB0 estimates, attributable to variable quality of age composition data, were found for some BC stocks. New SB0 estimates for two northern BC stocks exceeded those derived from catch-at-age assessment models, suggesting the latter could underestimate stock depletion. However, overlapping confidence intervals for the outputs of all three model types for all other stocks suggest multi-model inference may be a fruitful approach to herring SB0 estimation and formulation of precautionary fisheries management strategies. Confidence intervals for Schaefer and Fox SB0 estimates did not overlap with those of recent spawning biomass estimates for any BC stocks, strengthening the case for precautionary management.

March 9, 11:50 (S5-11635)

Natural and anthropogenic factors in the Guadalquivir estuary affect the abundance of anchovy in the Gulf of Cadiz (SW Spain)

Gustavo F. Carvalho-Souza[1,2], Marcos Llope[1,3], Francisco **Baldó**[1], César Vilas[4], Pilar Drake[5], Fernando Ramos[1] and Enrique González-Ortegón[1]

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The Gulf of Cadiz socio-ecosystem 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 on 18 years of monthly data from an estuarine monitoring program we (1) quantify the effects that natural (plankton, temperature, winds) and anthropogenic-influenced variables (freshwater volume, 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 contribute to the process of making the ecosystem approach operational in the Gulf of Cadiz.

March 9, 12:10 (S5-11663)

Factors for the fluctuations in the catches of oil sardine and Indian mackerel along southwest coast of India: Perspectives of fishery scientists and fishermen

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The oil sardine, *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* play key role in the nutritional security along the SW coast. The fishery showed wide fluctuations over the last 3 decades (Vivekanandan et al; 2009 and Kripa et al., 2015). Interaction with the fishermen and scientists reveals different views on the fluctuations in the Seminar on" Quality Management and Sustainable Fishing, 2016" . Government of India had fixed minimum legal size for catching sardine and mackerel. This paper examines the various hydrobiological features and human interferences affecting the vulnerability of the fishery.

Fishery scientists attribute incrase in sea surface temperature, climate change, El-Nino effect, hypoxia, shortage of phytoplankton, change in spawning season, exploitation of under sized fishes as the reasons. Manjusha et al; 2013 related coastal upwelling index to sardine production. Stephen, 2008 showed that presence of desired copepod species is important for mackerels. Fishermen complain that the large sized mechanized vessels with smaller mesh nets cause depletion of the stock. The ban on trawling for 47 days in June, July has provided a steady increase in sea wealth. The newly identified Indian chub mackerel (Abdussamad, 2016) can contribute potential fishery and may replace Indian mackerel. The unpredictable vagaries of nature can be guarded by protecting the spawning and juvenile stock and by strict regulations for commercial fishing for long-term sustainable fishery. The traditional practical wisdom of fishermen coupled with scientific theories can resolve the hydrometerological alterations and protect the pelagic fishery to posterity.

Keywords: Climate change, trawling ban, sustainable fishery

March 9, 14:00 (S5-11728)

A multi-model approach to understanding the role of Pacific sardine in the California Current food web

Isaac C. **Kaplan**[1], Tessa B. Francis[2], André E. Punt[3], Laura E. Koehn[3], Enrique Curchitser[4], Felipe Hurtado-Ferro[3], Kelli F Johnson[3], Salvador E. Lluch-Cota[5], William J. Sydeman[6], Timothy E. Essington[3], Nathan Taylor[7], Kirstin Holsman[8], Alec D. MacCall[6] and Phillip S. Levin[9]

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A recent workshop of the US Pacific Fishery Management Council conducted a review of ecosystem models that might be used to evaluate effects of Pacific sardine (*Sardinops sagax*) harvest on the broader California Current (US West Coast) ecosystem. This workshop found that "available ecosystem models are not sufficiently well developed to form the basis for an evaluation of the impact of sardine control rules on broader ecosystem impacts." Motivated by this call for improved modeling, a new Ocean Modeling Forum began to develop a California Current sardine case study (http://oceanmodelingforum.org/working-groups/pacific-sardines/). This case study primarily involved comparing predictions from a suite of ecosystem models, and we benefited from having models that differ in their complexity and the amount of time required to build and run them. We applied several model types: Ecopath (Koehn et al. 2016), a statistical prediction generalization (Pikitch et al.2012) based on 10 dynamic food web models, a Model of Intermediate Complexity for Ecosystem assessment (MICE, Punt et al. 2016) and an Atlantis end-to-end ecosystem model. The models identified key prey species (anchovy

Engraulis mordax in addition to sardine), and vulnerable predators such as brown pelicans *Pelecanus occidentalis*. Individual models predicted additional facets of the ecosystem response, such as declines in dolphins and flatfish in Atlantis when sardine were at low abundance. This case study explores the value of using multiple modeling approaches aimed at a single management issue. This work was conducted through the Ocean Modeling Forum, and as a component of an Integrated Ecosystem Assessment (http://www.noaa.gov/iea/regions/california-current-region/index.html).

March 9, 14:20 (S5-11751)

Evaluating harvest strategies for small pelagic fish

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Small pelagic fish (SPF) play a key role in marine food webs and support valuable fisheries. They also exhibit high-amplitude fluctuations in productivity, which present a challenge to fishery managers seeking to satisfy the needs of a valuable fishing industry and the requirements of marine food webs. A central debate in SPF management is whether adaptive management or precautionary, fixed-limit strategies are more effective for monitoring forage fish populations. For many SPF stocks, there is significant uncertainty in the type and frequency of recruitment, in the unexploited biomass of the population, and in the ability of assessments to detect changes in productivity. We use a simple SPF life history model and a simulation framework to test the performance of adaptive and fixed-limit harvest strategies in the face of these uncertainties, and to identify trade-offs among management performance measures. The effectiveness of management strategies depends on the management objectives they are meant to achieve; here we consider a set of performance metrics from the fish processing and fish oil industries, as well as broad ecosystem objectives that minimize risk. We anticipate that harvest strategy performance will depend on the type of recruitment variation and the ability of assessments to detect rapid changes in productivity. No single harvest strategy out-performed all others, but in general the collection of good-performing harvest strategies varied across plausible ecological scenarios.

March 9, 14:40 (S5-11746)

Evaluating alternative forage fish harvest control rules from a seabird perspective

Laura E. **Koehn**, Timothy E. Essington, Margaret C. Siple and Andre Punt

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Small pelagic fish (SPF) are a main prey source for many seabird species and collapses in SPF abundance can lead to negative impacts on seabird abundance, survival, and reproductive success with potential long-term negative consequences for seabird populations. Though SPF biomass fluctuations and collapses are largely naturally occurring, constant fishing pressure on SPF species can increase the magnitude and frequency of collapses. Therefore, we sought to determine if it is possible to manage SPF fisheries to minimize negative impacts to seabirds, in the face of fluctuations and continued fishing. Specifically, are there win-win management scenarios that sustain SPF fisheries and conserve seabird predators? We developed predator-prey models of a generic small pelagic fish and six generic seabird life histories to test the impacts of various SPF harvest control rules on population dynamics of different types of seabirds. Harvest control rules tested were all marginal changes in current practices to simulate realistic, plausible changes in management, including spatial and seasonal control rules. Seabird types modeled vary in breeding strategy, diving depths, foraging distances, and dependency on SPF species. In the models, both seabird survival and reproductive success are linked to SPF abundance. We anticipate that spatially restrictive management strategies will produce the greatest benefits to most seabird populations, as seabirds are known central place foragers. Results from this management strategy evaluation will highlight trade-offs between seabird and fishery performance measures, while also revealing strategies that perform poorly for specific types of seabird species to focus future regionally specific modeling efforts.

March 9, 15:00 (S5-11754)

A claim for precautionary adaptive management in upwelling systems. The case of Peruvian anchovy (*Engraulis ringens*) fishery

Mariano **Gutierrez**[1], Francois Gerlotto[2], Gary Vargas[1,3] and Arnaud Bertrand[2]

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Upwelling systems are subject to high climatic variability. Paleoecological reconstructions showed that pelagic fish populations presented variations not correlated to classic climatic indexes. Most of our knowledge is based on short-term time series where ephemeral correlation can be observed. Hence many 'ecological surprises' occurred. We should thus be modest about our genuine knowledge, particularly in the current context of global change. Although end-to-end modelling is needed in the context of ecosystem-based management, it is only based on current knowledge. Observation of changing ocean is thus critical. It needs to be adaptive to account for any ecosystem change. This is the basis for the Adaptive Precautionary Management (APM) applied in the Peruvian anchovy (*Engraulis ringens*) fisheries since the 1990s. APM is based on the closest attention to biomass and recruitment levels, distribution changes, spawning rates and environmental forcing. APM allows (and conducted to) temporal closings or cancellations of fishing seasons based on real time scientific information. Then the decline of anchovy catches observed in 2010, 2012, 2014, 2015 and 2016 is more the result of the APM adapted to every specific situation than an actual fishery-induced biomass decline. We analyzed 25 years of acoustic biomass, VPA estimations, catch data and legal documents to show that: (i) anchovy catches have been far below levels of standing biomass; (ii) large natural forcing induces changes in recruitment impeding the determination of anchovy virgin biomass; and (iii) APM focusing in the main specie (anchovy) is also a way to protect the whole ecosystem.

March 9, 15:20 (S5-11821)

The importance of fisheries independent surveys for an ecosystem approach to management of small pelagic fisheries

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Small pelagics are known to rapidly respond to environment forcing at multiple scales. Climate variability may affect the distribution and abundance of small pelagic fishes, their life cycle and trophic relations. While understanding these mechanisms is of fundamental importance in the long term, ability to predict trends with an acceptable level of certainty is still very limited, also in situation of data/capacity rich fisheries. In order to handle decision-making in situations of high level of uncertainty, the ecosystem approach to fisheries (EAF) promotes the adoption of adaptive management systems with monitoring and evaluation being an important part of it. Use of scientific surveys provides in situ observations that have the strength of being able to detect changes in ecosystem components almost in real time and thus being able to alert management authorities on these. On the other hand, stock assessment models often do not take into consideration environment related drivers and reliable time series of fisheries dependent data are often not available or partial. This contribution highlights the importance of fisheries independent surveys and provides examples from several developing countries where scientific surveys are jointly used at a national and regional scale for decision making in situations with a high level of uncertainty both because of the natural variability of resource abundance, on the one hand, and/or because of the lack of reliable fisheries dependent data, on the other.

March 9, 16:00 (S5-11830)

The contribution of natural mortality to the decline and recovery in forage fish

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Forage fish are a vital part of ecosystems, in part by supporting some of the largest fisheries, but also in part because of their role in food webs as prey for larger fish and other predators. One of the unresolved question about forage fish dynamics are their significant temporal fluctuations. These fluctuations are often contributed to changes in environmental conditions (such as temperature and primary productivity), by changing recruitment bursts. Recently, it has also been showed that fishing amplifies collapses on a global scale. Here, I show how changing natural mortality can additionally play an important role in forage fish fluctuations. Using a novel approach that incorporates size based mortality, I illustrate how natural mortality often increases, as populations of forage fish start declining, and conversely how mortality often is decreasing, when they are recovering. Fishing predators induces some of these temporal mortality changes and can thus be seen as anthropogenic changes in trophic control. I conclude that a holistic ecosystem analysis is required for a better ecological understanding of forage fish dynamics.

March 9, 16:20 (S5-11858)

Managing the Bay of Biscay anchovy: Fishery requirements vs sustainability given recruitment uncertainty

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After the collapse of the anchovy fishery in 2005, the need of a long term management plan became evident. The first plan was developed in 2008 based on spawning stock biomass estimates from spring surveys without any information on the upcoming recruitment. The TAC was set from July to June, just after the spring surveys, conditioned to keep the risk of SSB falling below Blim lower than 5%, given the unknown level of recruitment sustaining most of the fishery from January to June. This plan became operative in 2010 when the fishery was re-opened. A second version of the plan was defined in 2014/15 incorporating an autumn acoustic survey capable of forecasting the strength of next coming recruitment in January. Nowadays TACs are set from January to December, after the recruitment survey, with a similar level of risk for SSB levels. The addition of the recruitment index allowed gains on the Long term yield. Since the beginning, the Harvest Control Rules (HCR) defining the TACs have been defined through an interactive process between stake holders, managers and scientists. This allowed taking into account the needs for an economically minimum viable activity and for the actual fishing and market absorption capacity by inclusion of minimum and maximum TAC levels in the HCR. Testing the performance of different HCRs was produced through a management strategy evaluation (MSE) algorithm, taking into account main uncertainties in assessment and stock dynamics. Since 2010 the stock has well recovered and the fishery operates normally.

March 9, 16:40 (S5-11863)

Incorporation of environmental drivers in the prediction of pelagic stocks recruitment in the Baltic Sea using random forest algorithms

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The knowledge on environmental drivers of fish recruitment processes are essential for our understanding of population dynamics. Recent availability of data give chance to test a variety of predictors, however traditional statistical tests are often not enough flexible for complex biological data analysis. Current developments in machine learning provide an opportunity to apply novel techniques, which are able to handle non-linear relationships and interactions, often occurring in ecological data. In the current work, the use of random forest algorithms was proposed to investigate drivers of main pelagic stocks recruitment in the Baltic Sea (sprat in ICES subdivisions 22-32 and herring in subdivisions 25-32, excluding Gulf of Riga), which can be included in the stock assessment processes within the framework of ecosystem-based management. Data on different environmental components, e.g. spawning biomass of interacting pelagic stocks, total biomass of main predators or hydroclimatic environmental factors were used in the analysis, taking into account possible time lags. The random forest with additional features selection (Boruta algorithm) was run to extract the important and influential features for regression. Random forest for each investigated stock was then fitted and evaluated using cross-validation methods. Comparison of prediction accuracy achievable by random forest and traditional stock-recruitment models were conducted. Potential benefits of data mining application and further incorporation of environmental factors in the assessment of stocks were discussed.

March 9, 17:00 (S5-11867)

Ecosystem impacts of applying single-species versus multiple-species MSY in the Patagonian sprat fishery (*Sprattus fuegensis*) in the inner sea ecosystem of southern Chile

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The Patagonian sprat (*Sprattusfuegensis*; Jenyns, 1842) is a clupeid fish that it is distributed around the southern tip of South America: from 41ºS in the Atlantic shore, including Falkland Islands, to 41ºS off Chilean Patagonia, one of the largest estuarine ecosystems around the world. The austral sardine (as known in Chile), is the main species of a recently (since 2004) small-scale fishery operating in the inner sea of the Chilean Patagonia. As small pelagic fish (SPF), Patagonian sprat is a key component of the ecosystem, because it feeds on phyto- and zooplankton items, and at the same time, is a prey of large fish with economic importance for the artisanal fishery of the inner sea of the Chilean Patagonia. Also, it is important for other key species in the ecosystem like Magellan penguin (*Spheniscus magellanicus*), other marine birds, and marine mammals like sea lions (*Otaria flavescens*). Since 2013, Chilean fisheries are managed by setting annual quotas that drive/maintain the fishery to/at the maximum sustainable yield (MSY). However, MSY is estimated using single-species stock assessment models ignoring trophic interactions. This study contributes to advancing the ecosystem-based management in the fishery of Patagonian sprat by modelling the structure and functioning of the inner sea of northern Chilean Patagonia and estimating single-species MSY as well multiple-species MSY. Later the ecosystem impacts of applying each reference point is evaluated using food web simulations, under the hypothesis that applying single-species MSY in Patagonian sprat results in greater negative ecosystem effects than applying multi-species MSY.

March 9, 17:20 (S5-11873)

Management strategy evaluation for the Bay of Biscay anchovy long term management plan definition

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Modelling of major uncertainties in population and fishing dynamics are fundamental for reliable Management Strategy Evaluation. Present work describes the modelling work carried out for the bio-economic impact assessment of alternative Harvest Control Rules (HCRs) for developing a management plan for the Bay of Biscay anchovy, using FLBEIA software. The underlying general Harvest Control Rule (HCR) consists of exploiting a proportion of the estimated Spawning Stock Biomass and is operative for two alternative management calendars: July-June or January-December, the latter to test the inclusion of a recruitment index. The final shape of the rule is defined by some parameters such as the harvest rate, the biomass trigger points and the TAC maximum and minimum thresholds. The performance of the HCRs is evaluated according to the biological risks, probability of fishery closure, expected average catches and interannual stability of these catches. Economic indicators like discounted present value of landings are also calculated. Robustness of these rules given alternative recruitment models and quota shares among fleets is also tested. In general, the inclusion of an available recruitment index allows moving the management calendar from July-June to January-December and leads to higher (~5%) and more stable average catches, while reducing biological risks and the probability of fishery closure (by ~40%). Simulations also reveal little effect on biological risk of different quota shares among countries and the benefits of including minimum and maximum TAC levels to improve fishery performance. The simulation results facilitated the selection of the adopted HCR by stakeholders and managers.

March 9, 17:40 (S5-11876)

More than fifteen years of collaboration on the assessment of small pelagic fish off Northwest Africa: Lessons learned and future perspectives

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Ensuring the sustainable use of the small pelagic fish stocks and the sustainable management of the fisheries exploiting them is one of the greatest challenges that the countries in Northwest Africa face. These resources form the basis for important fisheries composed of a range of fleets of heterogeneous nature, originating from coastal states or beyond. Their economic importance for the countries in the sub-region are unique and they are key to food and nutrition security in Africa. At the same time, these resources are transboundary in nature, calling for joint action both with respect to monitoring and management.

Recognizing the importance of a collaborative and holistic approach for the provision of scientific advice to management, the FAO working Group on the assessment of small pelagic fish off Northwest Africa was launched in 2001 with the overall objective to assess the state of the small pelagic resources in Northwest Africa and make recommendations on fisheries management and exploitation options aimed at ensuring optimal and sustainable use of small pelagic fish resources for the benefit of coastal countries. The working group reports to the Fishery Committee for the Eastern Central Atlantic (CECAF), which operates under the aegis of FAO. This contribution will analyse the work of the working group since its inception, looking at the technical and institutional challenges that it has faced as well as its role in regional collaboration and its contribution to science based fisheries management in the sub-region from regional and national perspectives.

Session 6
Oral Presentations

Small pelagic fish and humans – Social, economic and institutional dimensions

March 7, 10:40 (S6-11959)

A simple bio-economic model of the effects of subsidies on small scale (pelagic) fisheries

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This paper will (1) briefly review key bio-economic insights on fisheries subsidies reported in the literature; (2) present new analysis of global fisheries subsidies data to determine how much of these subsidies are provided to small scale fisheries compared to their large scale counterparts; and (3) discuss the implications of our findings on the ability of small-scale fishers to be economically viable.

March 7, 11:00 (S6-10877)

A bio-economic model of small pelagic fishery in West Africa: The case of the sardinella fishery in Senegal

Aliou **Ba**[1,3,4], Christian Chaboud[3], Jörn Schmidt[2], Philip Cury[3], Malick Diouf[4] and Patrice Brehmer[3]

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A bioeconomic model of sardinella fisheries in Senegal is built. This model is produced to analyze the responses of the fishery (mainly small-scale units but other fishing units types such as industrials units maybe include if necessary) to economic (price, costs), biologic (growth, mortality, recruitment) and management (taxes/subsidies, licenses, spatial regulation) parameters. It focuses on the main small pelagic species caught in Senegal (*S. aurita* and *S. maderensis*). The model is based on an analytical spatial population dynamics model (obtained by virtual population analysis) and a spatial fleet dynamics model (Based on species and fishermen migration and the earnings expectations too). Main model's outputs are biomass, catch, revenue, labor income, private profit and economic rent, and also the spatial distribution of fishing units.

A first version of the calibrated model and the preliminary analyzes of the results will be presented.

Keywords: Small pelagic, fisheries, Senegal, modeling, bioeconomic

March 7, 11:20 (S6-11940)

Understanding the fishery and value chain of anchovy (Keta Schoolboys) in Ghana

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Anchovy (Engraulis encrasicolus - Linnaes, 1758) is one of the small pelagics being fished along the Ghanaian coast. The small fish is hugely important for both the natural and the social system. It serves as zooplankton predator as well as prey for many marine organisms. And anchovy, also known as Keta Schoolboys, is of crucial importance for many poor consumers in the country. In Ghana they are mainly targeted by Anlo-Ewe beach seine fishermen. The main season is between June and September influenced by the major upwelling period. After being caught, anchovy is often dried, salted or smoked, making shelf life in the tropical country long (up to 6 months). As it is possible to buy small portions, of which all parts are eaten, including the nutritious bones and head, the fish is extremely important for the nutrition security of many poor. The availability of the fish however is under pressure. The fish appears to be overfished, and increasingly different fisheries and different uses are impacting on the stock. The fish is also used as bait and as feed for aquaculture. In this paper we will from a biological, economic and social perspective investigate the challenges in the various stages of the chain from production (biological, environmental factors, governance challenges and institutions), marketing (perishability, hygiene, marketing infrastructure and institutions) and consumption (accessibility, affordability, contribution to food security). The paper will end with a discussion on the management of the value chain.

March 7, 11:40 (S6-11807)

Management of small pelagics in Atlantic Canada: A case study of herring and mackerel

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Herring and mackerel are important small pelagic fish in Atlantic Canada, both economically and ecologically. The most recent available data has the directed fisheries for herring and mackerel valued at an annual average of ~$41 million and ~$9 million dollars, respectively, from 2010-2014. Both species are used as bait in invertebrate fisheries comprising 62% of the ~$2.4 billion total landed value of fisheries in Atlantic Canada as of 2014. In addition to a targeted harvest under an agreed quota, both species are caught as part of an unregulated and unmonitored bait and/or recreational fishery. Both species are food sources for higher trophic levels, thus occupying an important role in the marine ecosystem. Notably, both species have experienced significant population declines: mackerel is considered to be in the "critical" zone and the Southwest Nova Scotia/Bay of Fundy spawning component of herring is the "cautious" zone of Fisheries and Oceans Canada's (DFO) Precautionary Framework, which measures stock health according to pre-agreed parameters.

Our analysis of the current science and management approaches for both species indicates considerable shortcomings. Significant gaps exist in monitoring fisheries activities and incorporating all fishing mortality in stock assessment estimates. Quotas are not set using precautionary limits or considering the role of these species, particularly as prey for other important marine fish, and given natural fluctuations in populations in response to environmental variables. We will present recommendations for actions based on current government policies which if applied, would help to ensure the health and recovery of these populations' abundance.

March 7, 12:00 (S6-11717)

A spatial based management system for the sandeel fishery in the North Sea

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We present: 1) a historic review of the North Sea sandeel fishery and management; 2) a new spatial explicit management plan, and 3) preliminary results from the evaluation and attempts to implement this new management plan.

North Sea Sandeel is a small pelagic species which differs from other pelagics by having a strong sediment association as it lies inactive buried into the sediment most of the year. During the 1970'ies a Danish industrial fishery developed and peaked with more than 1.2 mill. tons sandeel landed in 1997. Up until 2005 the fishery was unregulated but thereafter, a TAC system has been in place. From 2010 the North Sea was divided into seven distinct management areas, each with separate TAC's, and for the three largest areas with separate assessments and reference points. This area based management system has never been endorsed by the fishery and has led to a series of controversies between the fishing sector, management and advisory bodies. Disagreements are centered around the TAC level and a lack of flexibility in the management of the fishery caused by the area divisions. This paper presents a new spatial based management plan for the sandeel fishery developed by the industry. In this plan the reference biomasses are secured, not only via the TAC setting but also by restricting the fishery to a limited area of the sandeel distribution each year.

March 7, 14:00 (S6-11903)

Is closing the best option? The case of seasonal closure for sardine fishery in the Visayan Sea, Philippines

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The sardine fisheries is among the small pelagics that support the economy of many developing countries. In the Philippines, reports of massive stock collapse of some species of sardine population caused for alarm. In 2010, a 24% rate of decrease was observed.

Establishing close season is one of the management options that could help revive fish stocks. Fisheries Administrative Order 167-3 (Establishing a closed season for the conservation of sardines and herrings and mackerel in the Visayan Sea), was implemented by the country's Bureau of Fisheries and Aquatic Resources to address stock collapse and overexploitation.

This study was conducted to examine the effect of seasonal closure to different stakeholders in the sardine industry. A total of 102 small scale fishers, 50 processors and 53 traders were interviewed. Results show that different stakeholders of the sardine industry were socio-economically affected by the implementation of FAO 167-3.While it improved the stocks it also facilitated illegal fishing activities since most (65%) of the respondents doesn't have an alternative and supplemental source of livelihood. Though most small scale fishers were negatively affected by the closure, most of them (52%) believe that close season could be beneficial and are willing (50%) to continuously support its implementation. Most of them (41%) suggested that there is a need for its strict implementation. Some policy recommendations include continuous implementation of close season, modification on law enforcement strategy, more intensive information education and communication campaign, and provision of an alternative and supplemental livelihood during close season.

March 7, 14:20 (S6-11813)

A variety of effort management and its quantitative evaluation in the Pacific purse seine fishery targeting small pelagic fish

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Small pelagic fish (SPF) of chub mackerel, spotted mackerel, and Japanese sardine have been commercially caught in Japan over many years, and managed by annual total allowable catch (TAC) system since 1997. In order to prevent race-to-fish and excess of TAC, fishery associations of purse seiners have been implementing a variety of effort management for the operations off northeast coast of Japan mainly on a voluntary basis. This presentation reviews a variety of effort management implemented for SPF in Japan during 2011-2013. The effort management measures are, for example, day closures, limitation of when, where, and how many times the purse seiners conduct their operations, and also limitation of the target species. A notable characteristic in the effort management system is its plasticity. The limitation rule has been frequently adjusted with consideration for formation of fishing grounds, availability of fish, and weather and oceanographic conditions. The plasticity of the management rule would be generated from the characteristic of SPF: large spatiotemporal variation of its catchability. We then quantitatively evaluated potential effects of the effort management on the recovery of the chub mackerel stock and avoidance of race-to-fish. The evaluation was conducted by using generalized linear models that predict catch amounts under the effort management based on actual catch and effort data during 2011-2013.

March 7, 14:40 (S6-11902)

A values- and ecosystem-based management approach to the Pacific herring fishery conflict in Haida Gwaii, Canada

Mimi E. **Lam**[1], Tony J. Pitcher[1], Matthias Kaiser[2], Jeffrey Scott[1], Szymon Surma[1], Evgeny A. Pakhomov[1], Kate Millar[3], Lawrence Ward[1] and April SGaana Jaad White[4]

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We developed an innovative values- and ecosystem-based management approach (VEBMA) to examine the Pacific herring (*Clupea pallasii*) fishery in Haida Gwaii, Canada. Participatory approaches were combined with ecological modelling (EwE) to promote dialogue among indigenous communities and commercial fishermen within this contested fishery. We interviewed a cross-section of Haida Gwaii community members (n=47), who were asked to prioritize twelve values and select among four fishery management scenarios and five biomass cut-off thresholds. Scenario and threshold preferences were conservative, reflecting the highest ranked values of respect, responsibility, and interconnectedness, corresponding to precautionary, participatory, and integrated management, respectively. Significantly, we validated the VEBMA by showing that stated scenario preferences corresponded with scenarios ordinated by associated ranked values and scenarios with least modelled ecological impacts and risks. By making explicit the values that straddle the science-policy interface, VEBMA is a decision-support tool that exposes policy trade-offs and can facilitate collaborative governance among diverse stakeholders.

March 7, 15:00 (S6-11885)

Identifying stakeholder values in British Columbia's herring fisheries

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Debates about a fishery's management typically focus on descriptive quantities such as biomass, yield or revenue, ignoring the many normative considerations involved in decision making. While the science used to justify Pacific herring (*Clupea pallasii*) fishery openings in British Columbia (BC), Canada is hotly contested by First Nations (FNs), Fisheries and Oceans Canada (DFO), and the industry, the BC herring fisheries conflict stems also from the competing concerns of its stakeholders. To identify these concerns, I conducted interviews with industry members based in southern BC, using an innovative methodology to elicit from respondents their value priorities and preferences for management, informed by the results of ecosystem modeling. I compared my results with existing data from Haida Gwaii, BC residents, revealing correlations between respondents' values and preferences, identifying subgroups of respondents who share similar values, and describing recurrent themes offered by respondents, such as the distribution of benefits from fisheries and legitimacy of their governance. By making explicit the differences in stakeholders' values and preferences, a more complete picture of the BC herring conflict emerges, allowing decision-makers to consider the full range of stakeholder concerns and implement management plans reflecting them.

March 7, 15:20 (S6-11581)

Linking large-scale dam removal and forage fish restoration and conservation: Observations from the Elwha Dam removals

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Large-scale dam removal an emerging ecosystem restoration tool. While much effort has been placed on physical and biological attributes of watershed restoration associated with large scale dam removal projects, relatively little focus has been placed on associated nearshore ecosystem elements. Forage fish, including surf smelt, *Hypomesus pretiosus*, Pacific sand lance, *Ammodytes hexapterus*, and eulachon, *Thaleichthys pacificus*, are pelagic schooling fish that seasonally spawn on intertidal beaches and lower rivers of the northeast Pacific. All require a very specific grain size substrate for spawning. Large-scale dams may well disrupt this cycle by altering sediment delivery to potential spawning reaches. We examine the response in nearshore habitat use of these three species of forage fish following large-scale dam removal with a series of long-term studies associated with the Elwha dam removals.

Over a decade of study, forage fish response to dam removals appears to be complex, species dependent, and related to multiple factors including high interannual variability, geographic factors, life history characteristics, sediment composition and habitat suitability. Based on these findings we provide recommendations for including specific elements of nearshore ecosystem conservation and restoration for forage fish into future large-scale dam removal restoration and management planning.

March 7, 16:00 (S6-11836)

A social-ecological approach for the full utilization of pelagic species alternation around Japan

Mitsutaku **Makino**[1], Takaomi Kaneko[1], Shiroh Yonezaki[2], Shingo Watari[1] and Masashi Kiyota[2]

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Small pelagic fish fluctuate largely. In case of Japan, the cyclical fluctuations of chub mackerel, sardine, and anchovy have been observed, known as the species alternation phenomena. In the 1960s, chub mackerel, which is a profitable species, was high and many capitals had been invested to launch new processing plants. In the 1980s, up to 4.5 million tons/year of sardine was harvested, and they were utilized mainly as raw material for the processing plants. Without the accumulation of plants in the 1960s, such large amount of sardine could not be utilized in the society. In the late 1990s, the next cycle were coming and several strong year classes of chub mackerel were observed. However, fishers overfished these classes at early stage, and until now we have not observed the big increase of the chub mackerel around Japan. On the other hand, recently several strong year classes of sardine have come, i.e., the sardine stock is expected to increase soon. Because the processing plants built in the 1960s have already vanished, no social infrastructure is remained to utilize sardine stock. In other ward, society cannot utilize sardine. In order to avoid such situation, 1) the stock of chub mackerel should be increased steadily and speedily in order to facilitate the investment to the processing sector, and/or 2) the non-pelagic species, e.g., walleye Pollock, should be managed rigidly, so that processing sector can increase the capacity to develop new processing techniques or recipe for sardine.

Workshop 1
Oral Presentations

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in an ecosystem context

March 11, 9:20 (W1), Invited

Easy access to environmental data for analyzing environmental drivers of the dynamics of small pelagic fish

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Analyzing environmental drivers of the dynamics of small pelagic fish requires easy access to the the desired environmental data. Ideally this would mean being able to access the data from within the analysis application of choice, and to obtain only the needed subset of the dataset. We describe a web data service (ERDDAP) as well as a suite of related tools that provides just such an access to literally petabytes of environmental data. In ERDDAP, the data request is completely defined by an URL, so any program or script that can send an URL and receive a file will work with ERDDAP. Moreover, the requested subset of the data can be returned in a wide variety of formats. This means users can can request subsets of data by filling out a simple form in a web browser, or they can build the data access into diverse applications such as R, Matlab, Python, shell scripts, Java, Javascript etc. We will also demonstrate some pre-built tools that use the ERDDAP service for users not comfortable writing their own scripts - these include the "Environmental Data Connector" that provides a GUI interface to ERDDAP from within ArcGIS, Matlab, R and Excel; the "xtractomatic" and "rerddap" packages for R; the "xtractoMatlab" program for Matlab; and a Jupyter notebook that can be used with Python.

Workshop 2
Oral Presentations

Methods and techniques for sampling and assessing small pelagic fish populations

March 11, 09:10 (W2-11932), Invited

Delayed detection of productivity declines amplifies forage fish population collapses

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A key feature of small pelagic fish populations is their propensity to exhibit high fluctuations, often over decadal time scales. Because the marginal effect of fishing on dependent predators is likely greater at low than at high forage fish abundance, fishing should aim to minimize effects at low population sizes. We gathered time series of abundance estimates and fishery catches for to characterize stock collapses, to evaluate whether they occurred more frequently than expected based on population growth rates, and assessed how fishing might have contributed to those collapse. We find that collapses were common, showed no trend by decade, and were more frequent than expected based on chance. We attribute this finding to a delayed (or insufficient) management response to population productivity declines. We show how a more adaptive harvest control rule might minimize the frequency and extent of collapses. Improved ability to accurately forecast population fluctuations will benefit fisheries and conservation by reducing the risk of collapse while also reducing unnecessary fishery closures.

March 11, 09:30 (W2-11922)

Assessment of Pacific herring (*Clupea pallasii*) populations in the northeast Pacific Ocean

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Despite extreme similarities in demographics and life history, model inputs and stock assessment model structures for Pacific herring populations across Alaska, United States, and British Columbia (BC), Canada, vary greatly. Choice of assessment model for Pacific herring stocks reflect available data and survey types, which for each population are highly dependent upon the topography, remoteness, and environmental conditions of each region, as well as the government funding. By examining similarities and differences among survey methods and assessment model structures currently used across Alaska and BC, regions can identify benefits and drawbacks of alternative methods, which can lead to improved assessment methods and performance of management procedures. Due to the similarity in demographics across populations, cooperation and information sharing across regions can aid in improving management with reduced costs.

March 11, 09:40 (W2-11906)

BIOMAN: Anchovy DEPM surveys in the Bay of Biscay from 1987 to 2016

Maria Santos[1], Andrés **Uriarte**[1], Leire Ibaibarriaga[2], Guillermo Boyra[1] and Lorenzo Motos[1]

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The BIOMAN surveys series started in 1987, on annual basis, to monitor and assess the Bay of Biscay anchovy population. The main objective was to obtain a total biomass index of anchovy in spring in the Bay of Biscay by the Daily Egg Production Method (DEPM) as well as the biomass at age. In addition, the survey aimed at improving the knowledge on the spawning and reproductive biology of anchovy. In this presentation we report on the application of the DEPM to the Bay of Biscay anchovy from 1987 to 2016 describing the major methodological changes adopted, in the estimation of the total egg production and the spawning frequency. In this period the anchovy population showed high fluctuations, including a recent period of very low biomasses (2005-2009) in which the fishery was closed. The historical maximum was reached in 2015 with 181,063t (CV 0.10) and the minimum in 2005 with 4,832t (CV 0.20).The major variability in spawning biomass estimates arises from the assessment of the total Daily Egg production (mean 4 E+12 eggs per day, CV 0.78), while daily fecundity is far less variable (mean 94 eggs/gram of biomass per day, CV 0.22). The series is in agreement with the tendencies of other index as an acoustic survey performed at the same time and area to estimate as well total biomass index of anchovy, with an autumn survey to estimate the anchovy biomass of juveniles and with the tendencies from the integrated assessment carried out for this population at ICES.

March 11, 09:50 (W2-11935)

Recruitment Processes Alliance research on age-0 juvenile Walleye Pollock in the Gulf of Alaska and eastern Bering Sea

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Uncertainty about the fate of juvenile fishes continues to be a major impediment to understanding the recruitment process of many economically and ecologically important marine resources. Walleye Pollock (*Gadus chalcogrammus*), a semi-demersal gadid, support some of largest fisheries in the world and are a dominant trophic component in many Large Marine Ecosystems in the North Pacific and adjacent seas. NOAA Fisheries' Recruitment Processes Alliance (RPA) maintains field research programs that focus on understanding the role of age-0 juveniles in recruitment fluctuations of Walleye Pollock in the eastern Bering Sea and Gulf of Alaska. Multidisciplinary sampling includes CTD casts and net tows to collect zooplankton. Small-mesh midwater trawls are used to collect age-0 juvenile Walleye Pollock and other small neritic fishes. Some of the biggest challenges to collecting representative samples result from extensive geographic and vertical spatial distributions of age-0 juveniles, and seasonal increases in fish body size, schooling behavior, and swimming ability. Adaptations to gear configuration and sampling methodologies have been employed on our fisheries oceanographic surveys in an effort to mitigate these challenges. While the research focuses on understanding climate-mediated recruitment dynamics, considerable effort is also made to provide information relevant to forecasting year-class strength.

Workshop 4
Oral Presentations

Modeling migratory fish behavior and distribution

March 11, 09:10 (W4-11741), Invited

Reaching consensus on the growth–survival paradigm in early life stages of fish

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A paradigm in early life stages of fish holds that larger and/or faster-growing individuals are more likely to survive than smaller and/or slower-growing conspecifics. This "growth–survival" paradigm has received much attention in studies on recruitment dynamics of small pelagic fish over the past quarter century. However, contradictory results stemming from both field and laboratory studies across different ecosystems, taxonomic groups, and research laboratories indicate a need to understand, reconcile, and synthesize such contradictory results. This talk highlights our perspectives emerging from a symposium/workshop on "Growth–survival paradigm in early life stages of fish: controversy, synthesis, and multidisciplinary approach" held in Yokohama, Japan, in November 2015. The symposium participants discussed controversial issues on the paradigm (controversy), considered ideas for reconciling and synthesizing contradictory results based on a collective perspective from the different study groups (synthesis), and promoted a collaborative framework for field, laboratory, and modeling studies (multidisciplinary approach). During the following workshop, a conceptual framework for synthesis was proposed. Furthermore, we identified research avenues needed for future breakthroughs in studies on the paradigm. A total of 19 issues were summarized under 5 topic categories: (1) "predation mortality", (2) "endpoint", (3) "spatial and temporal scales", (4) "intrinsic factors", and (5) "miscellaneous". The overall goal is to improve our understanding of the growth–survival dynamics during early life stages of fish in order to facilitate the prediction of recruitment dynamics under climate changes. Reconsidering the growth–survival relationship is anticipated to improve the ecophysiological background in migration/behavior models for small pelagic fish.

March 11, 09:50 (W4-11744), Invited

Individual based modeling of fish migration and distribution

Geir **Huse**

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Understanding the spatial dynamics of small pelagic fish stocks, is key to understanding how they are affected by predators, prey and climate variability. From a mechanistic point of view, it is important to keep in mind that the distributions at the population level emerge from the behavior of individual fish. Spatially explicit individual based modelling are therefore a valuable tool for addressing how pelagic fish stocks respond to these different drivers. I present a general model approach for simulating fish behavior and distribution using individual based models, and show examples from simulation models focusing on key pelagics in the North East Atlantic. It is advocated that spatial full life cycle models should be developed for key fish stocks as a meeting place for model assumptions and observations and as a test bed for a multiple hypothesis testing approach.

March 11, 10:50 (W4-11958)

Modeling effects of weight and growth rate on the recruitment variability of Pacific saury (*Cololabis saira*)

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We examine the recruitment variability of Pacific saury (*Cololabis saira*), which is a commercially and ecologically important pelagic fish in the North Pacific, using an individual-based model combining a bioenergetics model and migration model. We parameterize the mortality rate with the length, weight, condition factor, growth rate and temperature. The annual survival rates calculated by the model are compared with recruitment per spawning biomass (RPS) derived from the stock assessment for 2002–2015. The RPS is well reproduced in the model, especially in cases parameterizing the mortality using the weight and growth rate. Temperature also causes variability in the survival rates, but mostly the indirect effect through the growth rate, instead of the direct effect on the mortality. In the presentation, we will show the contribution of winter-, spring- and autumn-spawned cohorts to the variability in the total stock abundance, and discuss their differences in the recruitment processes.

March 11, 11:10 (W4-11793)

Challenges for modeling migratory fish behavior and distribution: An example in the western North Pacific

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Fish behavior and fish migration controlling factors are still unknown. In the western North Pacific, recently, an ecological hot spot where many small pelagic fishes congregate. A quasi-steady jets bifurcate from the Kuroshio Extension is contributing to form the ecological hot spot. The jet flows parallel to the subarctic current and horizontally entrains the nutrient rich subarctic water. Additionally, the warm and saline water transported by the quasi-steady jet possibly contribute to deep wintertime mixed layer formation and hence nutrient rich water is supplied from the deep layer to the surface. These horizontal and vertical nutrient supplies resulted in high primary production that possibly create an offshore ecological hotspot in the western North Pacific. In this presentation, we will demonstrate how difficult to realistically imitate the fish congregation to the ecological hot spot as an example of challenges for modeling migratory fish behavior and distribution.

Workshop 5
Oral Presentations

Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies

March 11, 14:05 (W5-11784), Invited

Bioenergetics modelling to advance knowledge on life history traits and population dynamics of small pelagic fish: Illustration with anchovy and sardine in the Bay of Biscay and beyond

Martin Huret[1], Paul Gatti[1] and Pierre **Petitgas**[2]

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Advancing knowledge on the impact of environmental factors on growth and reproduction of small pelagic fish at the individual level, as well as on recruitment or distribution at the population level, requires mechanistic models based on physiology and integrating the whole life cycle. For that sufficient data are needed to correctly calibrate the bioenergetics at the individual level, and discriminate between species having similar habitats but different response in their life history traits and strategies. We here first review the data usually used to calibrate life cycle bioenergetics models. We then provide an example of model development for anchovy and sardine in the Bay of Biscay. Our bioenergetics model is based on the Dynamic Energy Budget (DEB) theory and is calibrated with original data on energy density at the seasonal scale. These data add a strong constraint on the parameterisation of the energy allocation between growth, storage and reproduction, and allows differentiation of the bioenergetics strategies between both species, in addition to size and weight. The anchovy model was declined in an Individual Based Modelling (IBM) framework to investigate the drivers of anchovy migration between habitats of different quality regarding fish bioenergetics response. The IBM was also run at the population scale to investigate the cause-and-effect understanding of total fecundity or recruitment variability. Finally we discuss remaining challenges towards model realism and determinism on the dynamics of energy allocation, as well as new opportunities from field and experimental data at successive life stages.

March 11, 14:40 (W5-11785)

Calibration of the DEB model for small pelagics. What data is needed and at which timescale?

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Bioenergetics approach aims at quantitatively assessing energetic condition and energy fluxes inside an organism from energy acquisition (feeding), to storage or allocation (to soma or reproduction). Such models are parameter rich and can be very tricky to calibrate, but the main impediment is certainly the available amount of suitable data at a pertinent time scale. Most processes (maintenance, growth, reproduction) occur at specific time scales that need to be resolved by the model. For example anchovy and sardine are indeterminate multiple egg batch spawners, meaning that their annual energetic investment is both a function of previously stored reserves and incoming resources. Moreover growth patterns in length and weight are not accurate enough to deal with the energetic condition of the fish, more specific data such as energy density are needed. We calibrated a DEB model for anchovy and sardine using field observed growth patterns and energy density measurements collected at two contrasted seasons (spring and autumn). Spring and autumn reflect minimum and maximum fish energetic condition respectively, as a consequence of distinct feeding and spawning histories over the past few months. We used an explanatory approach with scenarios to understand the link between bioenergetics and spawning strategies. We highlighted that, as well as total energetic investment in eggs, spawning phenology is a strongly structuring feature. We expect that other processes should be considered in the same way. Extensive field and laboratory experiments are needed to collect data for each process, i.e. feeding, growth and spawning at the appropriate time scale.

March 11, 14:55 (W5-11627)

Bioenergetics modeling of the annual consumption of zooplankton by pelagic fish feeding in the Norwegian Sea

Eneko **Bachiller**[1,2], Kjell Rong Utne[1], Teunis Jansen[3,4] and Geir Huse[1]

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4 Technical University of Denmark (DTU Aqua), Charlottenlund, Denmark

There are indications of top down control of zooplankton by pelagic planktivorous fish in the Norwegian Sea (NS). The present study uses bioenergetics modeling to estimate the annual consumption of the main zooplankton groups by the most abundant small pelagic fish feeding in the NS: the Norwegian spring-spawning (NSS) herring (*Clupea harengus*), blue whiting (*Micromesistius poutassou*) and Northeast Atlantic mackerel (*Scomber scombrus*). The study takes advantage of intensive sampling from surveys in the area in the period 2005-2010. By incorporating information about ambient temperature, seasonal growth and changes in the diet from stomach content analyses, annual consumption of the different zooplankton groups by pelagic fish can be estimated. Results show that NSS herring and NEA mackerel annually consume around 10 times their total biomass, whereas blue whiting consume 4 times their biomass in zooplankton. The three species can therefore consume around 110 million tonnes of zooplankton each year, which is more than the estimated consumption in previous studies. For NSS herring and NEA mackerel the main prey groups are calanoids and appendicularians, showing a peak in consumption during June and June-July, respectively. In contrast, blue whiting show a relatively constant consumption rate from April to September, consuming larger krill: euphausiids and amphipods. However, for the three predator species the relative importance of each prey group shows inter-annual variability. The estimates and their inter-annual and inter-specific variation are useful for understanding fundamental pelagic predator-prey interactions as well as to inform advanced multispecies ecosystem models.

March 11, 15:10 (W5-11916)

Combining lab and bioenergetic modelling approaches to better reconstruct growth from otoliths of *Sardina pilchardus* larvae

Laure **Pecquerie**[1], Susana Garrido[2], Susana Ferreira[2], A. Miguel Santos[3], Pedro Ré[2], Cristina Nunes[3], Gonçalo Marques[4], Tañia Sousa[4], Ronan Fablet[5] and Hélène de Pontual[6]

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Estimating age and growth of fish larvae in the field from otolith daily growth increments is often performed in recruitment and connectivity studies. However, distinguishable increments may not always be formed at a daily scale, which biases age and growth reconstruction. To better understand the conditions under which distinguishable increments are formed and reduce reconstruction bias, we propose to further develop, at the daily scale, a bioenergetic-modelling framework previously applied to the seasonal formation of fish otoliths. This model, based on Dynamic Energy Budget (DEB) theory, couples both otolith growth and opacity to the metabolism of the organism, as a function of food density and temperature conditions.

We apply the model to sagittae of Atlanto-Iberian sardine larvae *Sardina pilchardus* reared under laboratory conditions, at four different food levels (high, intermediate, low and starvation conditions). This experiment showed that increment deposition was significantly less than one per day. We tested the assumption that individuals do not deposit sufficient material of contrasted opacity for an increment to be formed at low food levels. Data on otolith diameter, number of growth increments, known age and total length were used. To calibrate and validate the model, we use data at i) high and low food levels, and ii) intermediate and starvation, respectively. Further investigation is required to better understand otolith opacity as a function of feeding timings and photoperiod. We discuss the current potential contributions of this model to growth and feeding conditions studies in the field.

Keywords: otolith daily growth, opacity, bioenergetics, Dynamic Energy Budget (DEB) theory, growth reconstruction, larvae, *Sardina pilchardus*

March 11, 15:25 (W5-11918)

Ecophysiological models of foraging and growth of small pelagic fish: Progress and challenges

Myron **Peck** (and W5 participants)

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This talk presents a synthesis of laboratory and field data collected to help understand the ecophysiology (growth, feeding, metabolism) of small pelagic fish and how such data have been incorporated into mechanistic, biophysical models. Due to the challenge of maintaining these fish in the laboratory, our knowledge on the ecophysiology of these (mostly clupeiod) fish is relatively poor compared to other groups (e.g. salmonids, gadoids) with the exception of studies on herrings. For example, very few studies have examined the effects of multiple, interacting physical factors on rates of feeding and growth. Similar to other fishes, the early juvenile period (just after larval metamorphosis) is the life phase where the fewest studies have been performed. We compare temperature- and life-stage specific rates of feeding, growth and metabolism within and among species based on controlled measurements in the laboratory and patterns of seasonal energy allocation revealed from field survey campaigns. The foraging and growth subroutines from various published models of small pelagic fish (particularly models on various anchovy and herring species) are compared with emphasis on how temperature and prey influence growth. Realistic depictions of thermal windows, seasonal cues for life cycle scheduling, and prey thresholds for growth dynamics will be necessary to create models which can provide robust projections of how climate change may impact on the distribution and productivity of stocks of small pelagic fish.

Workshop 6
Oral Presentations

Remote sensing and ecology of small pelagics

March 11, 09:40 (W6-11911), Invited

Mapping small pelagics, fisheries and the primary production they require

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The estimation of primary production (PP) was among the first remote sensing applications of direct use to fisheries research. This contribution will review (i) attempts to relate observed fisheries catches to PP estimates from remote sensing, with emphasis on small pelagic fishes, and (ii) the related concept of 'primary production required by fisheries' (PPR). Global maps of PPR will be presented, based on the 'reconstructed' catches of small pelagics and other marine fish and invertebrates mapped onto their distribution range maps given constraints to fleet operations, and maps of PP from remote sensing. The major features of the PPR maps will be described and explained and explained.

March 11, 10:20 (W6-11908)

Inter-annual variability in *Sardinella longiceps* in response to ENSO event in the coastal waters of India

Grinson **George**[1], Muhammad Shafeeque[1], Nandini Menon[2], Shubha Sathyendranath[3] and Trevor Platt[3]

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Sardinella longiceps (sardine) is a small pelagic fish dominating in the marine landings of India. An analysis of the effort involved for catching sardine showed a decreasing trend in catch per unit effort in recent years. The inter-annual variability in sardine landings is not completely driven by variability in effort. There are a lot of seasonal and inter-annual environmental changes in the coastal waters of India where the fish are abundant. The environmental factors are major drivers for large-scale variation in fish abundance. Here, we try to analyse remotely-sensed chlorophyll-a concentration and Sea Surface Temperature (SST) data to explore the possible causative factors which affect fish abundance. The maximum sardine catch reported in India was 0.72 million tonnes in 2012, with a decreasing trend afterwards. We assume that the sardine catch per unit effort reflects its abundance. Sardine gets recruited into fishery the same year it spawns and sufficient crafts are available to harvest the abundant fish. The monthly SST anomaly after 2012 showed an increasing trend. There is a major change of nearly 2-2.5 ^{O}C in the SST anomaly during 2015- 2016 which coincide with El Niño-Southern Oscillation (ENSO) event. An alteration in the Walker circulation pattern during ENSO event results in a net heat gain during summer months in the coastal waters of India. Breeding of sardines also occurs during summer monsoon. Therefore, it appears that the inter-annual variability in sardine is due to unfavourable environmental conditions resulting from ENSO-associated temperature variations.

March 11, 11:00 (W6-11951), Invited

Inter-annual variability of upwelling, nutrients and planktonic community net metabolism in the southern Humboldt Current System: Management implications for pelagic fisheries

Renato A. **Quiñones**[1,2], Bárbara G. Jacob[1], Giovanni Daneri[3], Fabián J. Tapia[1,2,4], Odette A. Vergara[1,2], Marcus Sobarzo[1,2], Eduardo Hernández-Miranda[1] and Rodrigo M. Montes[1]

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The Humboldt Current System (HCS) is a highly productive and biophysically variable ecosystem. Spatial/temporal ecosystem variability is crucial to resource sustainability, which is further emphasized by climate change and other stressors. To explore the biological response to changes in inorganic nutrient inputs and upwelling event duration on the continental shelf off south-central Chile (~ 36° S), we analyzed a monthly time series of wind satellite data from 2003 to 2013, direct observations of oceanographic parameters and *in situ* experiments of primary productivity (PP) and community respiration (CR). Monthly time series of *in situ* PP from two coastal bays were also examined. The spatial and temporal variability of nutrients and chlorophyll was also assessed using a ROMS-PISCES coupled model and temporal/spatial chlorophyll variability was analyzed using SeaWiFS satellite data. The seasonal cycles of PP and community net metabolism (PP/CR) strongly depend on the interplay between precipitation and river runoff in winter and the upwelling of cold nutrient-rich water into the euphotic zone in spring-summer. A drop in freshwater input in the coastal zone since 2007 has resulted in lower Si:N ratios in the mixed layer, which has negatively affected PP and altered carbon fluxes. Furthermore, phytoplankton production and biomass have been negatively affected by the lengthening of upwelling events since 2009, which has likely enhanced the export of nutrients and organic matter offshore and weakened nearshore stratification. We discuss the implications of these findings on temporal and spatial variability for the management of small pelagic fisheries in the southern HCS.

March 11, 14:00 (W6-11912), Invited

Prediction of species distribution and abundance using high quality satellite products in combination with Bayesian networks

Jose A. **Fernandes**, James Dingle, Trevor Platt and Shubha Sathyendranath

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The EU's Common Fisheries Policy was recently reformed introducing an obligation (to be phased in over time) to land all fish catches. Member states and fishers have quotas for the catch of different fish species they can land. If they catch too many of a fish species with a low quota, because it is present in high numbers where and when they are fishing, the vessel will have to stop fishing even if they still have quota remaining for other species. It is the responsibility of the fishermen to plan for the best use of their fishing rights, but it is difficult for them to foresee how this could be achieved. Within the fishing industry there is considerable concern of the socio-economic impacts. Satellite Earth observation (EO) at PML is generating products of high quality and resolution (up to 4km and 8 days averages) of temperature, chlorophyll, primary production and optical water quality. Past application of satellite data to fisheries has been limited to total fish production and specific species due to the lack of detailed fisheries data to test applications of satellite products. However, fish data collated from surveys conducted over 26 years by European fisheries agencies provide a unique opportunity to test the viability of predictions using satellite data to guide more efficient and policy compliant activities, by the fishing industry. Our work will compile both sources of data and then link them using Bayesian networks to establish probabilistic relationships between past fish distribution and environmental predictors inferred from satellite data. This could allow near real-time forecasting of the best fisheries grounds balancing multiple constrains (e.g. ecological issues, fisheries costs and policy restrictions).

March 11, 14:40 (W6-11928)

Application of phytoplankton biomass as an aid in management of marine resources of the southeastern Arabian Sea

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Coastal waters of Arabian Sea are major upwelling zones during the southwest monsoon season. Upwelling in the southeastern Arabian Sea (SEAS) affects the productivity of this region and hence the economy of coastal India.

The ECMWF ERA-Interim reanalysis data winds at 0.25^o x 0.25^o spatial resolution and AVHRR monthly SST data at 4.0 km resolution will be used to study the influence of the strong monsoon winds on lowering of SST.The depth of 20°C isotherm (D20) will be used to understand the subsurface thermal structure of the SEAS as per Ishii *et al*. (2005, 2006). Monthly sea level anomaly (SLA) data at 0.25^o x 0.25^o spatial resolution will be used to study the sea level variability in the SEAS. Upwelling intensity will be estimated from Ekman mass transport which is perpendicular to the direction of wind in the region.

The seasonal and inter-annual variations in the fish landing data of the major pelagic herbivorous fish *Sardinella longiceps* (Indian oil sardine) will be compared with the variations in chlorophyll as the variations in the phytoplankton biomass are expected to reflect on the fish catch.

Analyses will be carried out with a climate change perspective, dividing the years into good and bad monsoon years. In SEAS, there exists a fishermen population which is solely dependent on the catch of the small pelagics in the coastal waters. Better understanding of the inter-annual variability of the phytoplankton and herbivore fishery dynamics is essential in the planning and management of the livelihood of the fisherfolk.

Workshop 7
Oral Presentations

Simulation approaches of forage fish populations for management strategy evaluations

March 11, 14:15 (W7-11962), Invited

Characterizing small pelagic fishes in management simulations: Examples from the US West Coast and South Africa

André E. **Punt**

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Management Strategy Evaluation is increasingly becoming the method of choice to provide fishery and conservation managers with information on the advantages and disadvantages of candidate management systems, including the likelihood that such systems will achieve goals related to ecosystem objectives, such as the preservation and recovery of depleted predator populations. However, the reliability of this information depends on how well the predator and prey populations are represented in the operating models on which projections are based. Operating models can include many features that can qualitatively impact operating model outputs, but temporal and spatial variability, including regime shifts in productivity, of prey populations are amongst the most consequential. The properties of two sets of operating models are contrasted. The operating model developed to evaluate harvest control rules for Pacific sardine off the west coast of North America is spatially structured and includes regime-shift like changes in productivity, while the operating model developed to contrast candidate harvest control rules for sardine and anchovy off South Africa allow for stochastic variation (but not regime shifts) in recruitment strength and well as changes over time in the spatial distribution of sardine. The outputs from the two sets of operating models include changes over time in pelican numbers in the Southern California Bight and numbers of African penguins. The consequences of ignoring spatial structure and temporal variation in productivity on predictions of impacts on predator populations are highlighted and some best practices identified.

March 11, 14:30 (W7-11963), Invited

Predicting temporal mortality changes from size structure

Nis S. **Jacobsen**

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Contemporary fisheries management often assumes that natural mortality is constant when assessing exploited fish stocks. This assumption can possibly cause incorrect estimations of fishing mortality and reference points of a stock when mortality is changing temporally. One of the biggest problems when estimating natural mortality is separating it from fishing mortality. A possible solution to this problem is that the two types of mortality often differ in the way they affect size classes. Consequently, changes in size structure can be used as a proxy of the relative contributions of the two types of mortality. Here I show how to estimate natural and fishing mortality of a forage fish species by observed changes in size structure by using a simple size based model. I estimate mortality on a simulated population, and I accurately separate fishing mortality and natural mortality based on a simulated survey with error and observed catch. The estimation is compared with simulations where 1) fishing selectivity changes over time, and when the estimation model assumes mortality is constant. The method is useful to the assessment of fisheries where ageing, diet composition and predator abundance is not available.

March 11, 14:15 (W7-11961), Invited

Simulating forage fish dynamics for MSE: A nonlinear forecasting perspective

Jin **Gao**[1,2]

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Non-linear dynamics is ubiquitous in fish time series. Non-linear forecasting is a general method that makes use of the non-linear behavior of populations. It is based on the Taken's theorem stating that times series can be fully reconstructed using its own lagged variables as proxies. It is a non-parametric method that has been found to give better out-of-sample forecast ability in many systems. This method provides a straightforward way to incorporate external variables and perform scenario explorations under different harvesting strategies and possible climate conditions. An overview of the non-linear forecasting framework and then a simulation-validation study in a simple two forage fish system will be presented. The performances of different management strategies will be also evaluated.

Abstracts
Poster Presentations

Session 1
Poster Presentations

Environmental control of spatio-temporal changes in population size, distribution and migration of small pelagic fish in the ecosystem context

S1-P1

Spatial and temporal variability in nearshore forage fish communities in the Strait of Juan de Fuca

Kinsey **Frick**[1], Anna Kagley[1], Kurt Fresh[1], Eleni Petrou[2], Larry Ward[3], Doug Morrill[3] and Jameal Samhouri[1]

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Forage fish are ecologically and economically important as the foundation of the piscatorial food web, and as the focus of commercial fishing in many locations. Despite acceptance of these ideas, the population dynamics of forage fish in the Salish Sea are poorly understood. Over nine years of monthly beach seine sampling (April – September) at 24 sites along 70 kilometers of coastline in the Strait of Juan de Fuca, we have observed high variability in catch across years, sites, and seasons. Forage fish species dominate net presence, and we have documented the existence of species previously unknown to the region. The influence of individual species varies, yet can drive the fish assemblage structure. We explored the effects of temporal and spatial variability on forage fish abundance and community composition using a Bayesian hierarchical modeling framework and multivariate analyses. Three forage fish species dominated our catch and are the focus of additional investigation: Pacific Herring (*Clupea pallasii*), Pacific Sand Lance (*Ammodytes hexapterus*), and Surf Smelt (*Hypomesus pretiosus*). These show species-specific variations across years, seasons, and sampling locations. Other forage fish species appear to increase when these populations are depressed. We will expand on the current distributional descriptions through population dynamics analyses based on genetics for the common forage fish species. Stable isotope analyses will further define forage fish population structure within the Strait of Juan de Fuca and throughout the Salish Sea. This approach may reveal unanticipated risks to the ecosystem that can be mitigated through management revision.

S1-P2 CANCELLED

Nearshore forage fish populations in the context of Elwha River dam removals

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Removal of two dams on the Elwha River, Washington, is expected to help restore natural sediment processes to the coastal environment near the river mouth. Since 2006 we have been collecting data on shallow subtidal (nearshore) fish communities near the Elwha River and at reference sites in the Strait of Juan de Fuca to assess the effects of dam removal on nearshore fish communities. Ecologically important forage fish spawn and rear, and juvenile salmon migrate through these areas. Trends in species richness and abundance were consistent throughout, with reference areas possessing more species and overall abundance of fish than sites near the river mouth. Forage fish dominate our samples across years, but the influence of individual species varies, and can drive fish assemblage structure between sampling regions. We explored patterns of forage fish abundance in relation to dam removal, environmental variables, site characteristics, and season using a Bayesian hierarchical modeling framework and multivariate analyses. Forage fish abundance has increased at sampling sites since dam removal. Pacific Herring (*Clupea pallasii*), and Pacific Sand Lance (*Ammodytes hexapterus*) have shown the greatest increases over all areas. Surf Smelt (*Hypomesus pretiosus*), also common, has increased 40-fold in the impacted region with the additional deposition of riverine sediment. Overall abundance of forage fish has increased more following dam removal within the impacted region than in reference regions. We will continue to monitor nearshore fish populations as the system evolves towards a more natural sediment regime.

S1-P3

Seasonal evolution of oceanographic parameters in relation to *Trachurus picturatus* landings index in Tenerife (the Canary Islands, Spain)

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The artisanal purse-seine fishery in the Canary Islands is constituted by an average of 14 vessels per year. The main targeted species by this fleet in the Archipelago (in order of importance in landings) are: the Atlantic chub mackerel *Scomber colias,* the blue jack mackerel *Trachurus picturatus,* the European pilchard *Sardina pilchardus* and the round sardinella *Sardinella aurita*. This fleet does daily nocturnal fishing trips, attracting the small pelagic fish by using lights. More than 65% of the total landings of the fleet are produced in the Tenerife Island. This study aims to evaluate environmental relations between some oceanographic parameters and the landings of *Trachurus picturatus*. Quarterly mean values of SST (ºC), SSTA and concentration of chlorophyll *a* (mg/m^3) were obtained for the area corresponding to the Island between January 2001 and December 2014 (from open databases), and compared with the quarterly evolution of an index of the landings of the studied species. In order to assess the seasonal variation of these catches, Principal Component Analysis (PCA) was performed.

S1-P4

Climate change and pelagic fisheries predictions in Chile (CLIPESCA)

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One of the priorities adopted in national and global fisheries policies is the progressive implementation of an ecosystem approach for fisheries management (EAF) to ensure the sustainability of aquatic resources. Climate Change (CC) will affect fisheries development in the EAF context and it is important to consider such effects at regional and local scales. The conceptual approach of CLIPESCA program is to link historical and future scenarios of CC with their external environmental (physical) and socio-economic (fishing effort) drivers to assess the impacts on the pelagic fisheries (anchovy, sardine, common sardine, jack mackerel and swordfish) in Chile. The aim of CLIPESCA is to develop a forecast system to explore how CC will affect the future pelagic fisheries resources. The methodology used in the project execution was based on: collection of historical spatial-temporal environmental and fisheries databases; development of predictive models based on historical data (neural networks and generalized models); dynamics (ROM and 4xCO2 scenario) and statistical (Delta Method and A2 scenario) downscaling of oceanographic conditions in the study areas; forecast of pelagic fish catch and relative abundance based on the prediction models forced with the future ROMS and Delta Method outputs; and finally a web site was built and contains all databases, models and forecasts by pelagic fisheries in the study areas (www.clipesca.cl).

S1-P5 CANCELLED

Multi-temporal analysis of upwelling/downwelling dynamics in the South China Sea and potential implications for coastal fisheries

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Many efforts have been geared towards the investigation of specific upwelling events and their mechanisms in the South China Sea (SCS) generally over a seasonal time scale. However, issues related to changes in the intensity and predictability of these changes over longer (inter-annual, decadal and multi-decadal) timescales have generally received little attention. Given the physical oceanographic and biochemical significance of upwelling especially in coastal systems, multi-temporal (seasonal, inter-annual and decadal) analysis of changes in upwelling patterns and intensity could serve as an important indicator for understanding, tracking and predicting regional ocean-climatic variability. In the present study, geo-statistical methods (including GIS mapping, least square regression analysis, cumulative deviations test and simple averaging techniques in Ms. Excel) have been applied to analyze a 47-year time series of upwelling indices (1967-2014) generated for four coastal locations in the northern section of South China Sea (Ndah 2016). It has been found that despite the significance of high frequency seasonal and inter-annual variability of upwelling/downwelling in the SCS, low frequency long term patterns of variability (multi-annual and decadal) are however the statistically dominant source of variability in terms of magnitude. Overall, results of trend analysis reveal that the intensity of upwelling peaked in 1980 and has been on a decline ever since, with the decline intensifying in 1990 in two zones (off Fujian and Hanoi), and in 2004 (off S.W Taiwan). It is therefore evident that something must have initiated the weakening upwelling in the northern coastal zone of the SCS, and these requires further investigation. Finally, the potential implications of these long term changes on coastal fisheries have been explored.

S1-P6

The effect of wind strength and variability on the Dipolog–Sindangan Bay upwelling system, Philippines

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Environmental variability plays a key role in determining fish abundance and recruitment in coastal upwelling systems. Dipolog–Sindangan Bay in the northern Zamboanga Peninsula has been established as an upwelling site, with an extensive small–pelagic fishing industry dominated by sardines. The objectives of this study are: to determine the magnitude of curl–driven and coastal upwelling in Dipolog–Sindangan Bay, to characterize the temporal variability of upwelling, to establish its relationship with upwelling intensity and productivity as well as total sardine catch. Coastal and curl–driven upwelling transport estimated from a high resolution atmospheric model dataset (COAMPS) available for one upwelling season (2007–2008), found that curl–driven upwelling was the primary mechanism for upwelling in the NZP. Using the same dataset, alongshore winds and curl–driven upwelling were found to be correlated, which allowed the use of alongshore winds from a low–resolution wind dataset (CCMP) available for 13 upwelling seasons (2002–2014). The variability at low and high–frequency temporal scales for alongshore winds and upwelling were calculated using wavelet spectrum analysis. There was strong intraseasonal and interannual variability between monsoon seasons, however there was no clear relationship between wind variability and upwelling intensity (SST) and productivity (cholorophyll). El Niño years tend to have higher sardine catch rates than La Niña years, although exceptions did exist. On an interannual scale, SST and chlorophyll were highly influenced by wind strength as modulated by ENSO, while the MJO index had a significant relationship with intraseasonal wind strength and variability.

S1-P7

Influence of the climatic oscillations on the sardine off Northwest Africa during the period 1976-2014

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Many studies suggest an important influence of the global climates indices on the abundance of small pelagic fishes. The three most important climates indices from North Hemispheric are: North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO) and Antarctic Oscillation (AO). The main aim of the present study is understand the effect of those climate oscillations on the relative abundance of sardine from Western African. We performed different regression models between Capture per Unit of Effort (CPUE) of sardine from this area as dependent variable versus NAO, AMO and AO as independent variables. The implications of these results in a context of global climate change are discussed.

S1-P8 CANCELLED

Age and growth of Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758) in Morocco's Atlantic region

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The Atlantic horse mackerel is a Carangidae exploited by different gears along the Moroccan coasts. In this work, we study the age and growth based to the sizes frequency distribution in the Moroccan Atlantic area. The samples were collected during the Russian commercial and acoustic surveys of the pelagic fish, between Cape Boujador (26°N30') and Cape Blanc (21°N00'). These surveys cover the period from 1962 to 2010. About 99 5975 specimens ranged from 5 to 45 cm of the total length were examined. The Length-frequency data collected are weighted to total catch of sampled stations and analyzed by decade with FISAT software (FAO-ICLARM Fish Assessment Tool). The estimated parameters of growth using the equation of Von Bertalanffy show an interdacadales fluctuations, they are as follows:

1960s: L_∞= 38.95cm; K= 0.24an^{-1}; t_0= -0.83

1970s: L_∞= 44.85cm; K= 0.20 an^{-1}; t_0=-0.89

1980s: L_∞= 47.25cm; K= 0.17 an^{-1}; t_0=-0.95

1990s: L_∞= 42.91cm; K = 0.22 an^{-1}; t_0=-0.85

2000s: L_∞= 40.57cm; K= 0.24 an^{-1}; t_0=-0.83

Key words: *Trachurus trachurus*, growth, Atlantic, Morocco

S1-P9

Quantification and causes of two incidents of fish kill of Icelandic summer-spawning herring (*Clupea harengus*) in the winter 2012/2013

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The Icelandic summer-spawning herring (*Clupea harengus*) stock overwinters in large and dense schools like other herring stocks. In the winter 2012/2013, around 300 thousands tonnes, or ~70% of the spawning stock, overwintered in a fjord west of Iceland. The inner part of the fjord, where the herring was located, is separated from the outer part with a shallow threshold, a natural barrier and road build up with a 210m long bridge. This creates strong tidal currents under the bridge. On December 14th and again February 1st, mass mortalities of herring took place there where the sea floor and the shores were covered with dead herring. Results of field works on the shores and on a small boat with video recordings and cameras few days after the incidents indicated that total 53 thousands tonnes had diet during these two incidents, or quantity at similar magnitude as the total catch from the stock that year. Measurements of environmental conditions few days after and around the incidents showed that the oxygen saturation was generally 20-40% but as low as 15% (1.1 ml l^{-1}). The weather was calm and cold prior to both incidents. The most likely explanation for mortalities was oxygen depletion as results of respiration of the large herring biomass, limited atmospheric-water gas exchange due to calm weather and sea ice on part of the fjord, limited circulation and mixing of water masses coming in and out via tidal currents, and aerobic decomposition of dead herring in the latter incident.

S1-P10

Using otolith shape analysis to quantify changes in stock distribution and migration of Atlantic herring in Newfoundland

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Newfoundland's marine environment has undergone a period of change over the last several decades, characterized by warming temperatures and shifts in species assemblages. During this period, populations of Atlantic herring (*Clupea harengus*) found in the coastal waters surrounding the island have experienced shifts in stock composition, reduced abundance, and suspected changes in migration and distribution patterns. While environmental changes have been correlated with shifts in herring population dynamics, examining the nature and cause of distribution changes presents a greater challenge. To quantify these changes and potentially link them with environmental drivers, we used the ShapeR package to delineate stocks using an otolith shape analysis. As expected, the results of our initial analysis have shown a significant difference between the otolith shape of herring from the north and south coast of Newfoundland. With this analytical tool, we plan to conduct a retrospective analysis encompassing otoliths collected from a range of times and locations in order to examine shifts in the distribution of herring and explore potential environmental drivers of these shifts.

S1-P11

Seasonal evolution of oceanographic parameters in relation to small pelagic fish landings index in the Canary Islands (Spain) from 2009 to 2015

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The main targeted small pelagic fish species in the Canary Islands (in order of importance in landings) are: the Atlantic chub mackerel *Scomber colias,* horse mackerels *Trachurus* spp.*,* the European pilchard *Sardina pilchardus* and sardinella *Sardinella* spp. This study aims to attempt to evaluate seasonal relations between some oceanographic parameters and these landings. Quarterly mean values of SST (ºC), SSTA and concentration of chlorophyll *a* (mg/m^3) were obtained for the area between January 2009 and December 2015 (from IGOSS-IRI and GIOVANNI databases), and compared with the quarterly evolution of an index of the landings (from official sale-notes). Factor analysis was carried out in order to assess the seasonal variation of these catches.

S1-P12 CANCELLED

Synchronization of the mean temperature of the pelagic catch (MTpC) with North Atlantic climate variability

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We investigated whether the pelagic fish communities of NE Atlantic and the Mediterranean respond to the climate variability of the North Atlantic. The mean temperature of the pelagic catch method (MTpC) that is based on the median temperature preference of each species weighted by its catch, was used. The annual landings of the fish species of the Bay of Biscay, the Celtic Sea, the waters west of Scotland, the Faroe Plateau and Icelandic waters were extracted from ICES and those of the western, central and eastern Mediterranean from GFCM (1950-2010). MTpC increased in the Celtic Sea, the waters west of Scotland and the Faroe Plateau and declined in the Bay of Biscay and Icelandic waters. The rate of MTpC increase was 1.05˚C, 0.92˚C and 0.72˚C per decade in the Celtic Sea, the waters west of Scotland and the Faroe Plateau, respectively. MTpC was positively correlated with the AMO in the Celtic Sea and the waters west of Scotland and negatively correlated in the Bay of Biscay and Icelandic waters; no correlation emerged from the Faroe Plateau. A positive relationship of MTpC with the NAO was observed for the Celtic Sea and a negative one for Icelandic waters. The rate of MTpC increase was 0.29˚C, 0.29˚C, and 0.25˚C per decade in the western, central and eastern Mediterranean, respectively. MTpC was positively correlated with the AMO in all three sub-regions, whereas it was negatively correlated with the NAO in the western and central Mediterranean.

S1-P13

Estimating the contribution of single nursery areas to the overall herring (*Clupea harengus*) population in the western Baltic Sea by otolith chemistry

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Coastal areas provide essential spawning and nursery habitats for many ocean-going fish species. However, these habitats are often highly impacted by multiple anthropogenic threats.

The Western Baltic population of Atlantic herring (*Clupea harengus*) is an economically and ecologically important component of the Baltic Sea ecosystem. It performs extensive spring migrations into inshore spawning grounds and shows a distinct homing behavior returning to particular spawning grounds every year. Attributed to early life stage mortality, herring recruitment decreased in the western Baltic Sea during the past two decades. Since major drivers and stressors for herring reproduction are potentially introduced on the local scale of spawning and nursery grounds, the knowledge of the contribution of juvenile habitat to the adult population is essential but challenging to investigate.

To identify the origin of herring recruits, we used elemental fingerprinting in herring otoliths to detect differences in the chemical composition based on varying water chemistry in particular spawning areas. Cluster analysis revealed a distinct chemical separation between juvenile herring caught in nursery areas along a West – East coastal gradient in the Baltic Sea.

Several element concentrations differed significantly among areas. Further trace element analyses of 0-group and adult herring otoliths will prove the ratio of individuals that originated in a certain nursery area. Otolith chemistry is considered a valuable tool for identifying the origin of herring offspring and evaluating the contribution of different spawning areas to the adult population which could lead towards a more directed management of important spawning grounds and nursery areas.

S1-P14

Geographic detection of the Regime signature

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Sardines and anchovies exhibit wide interdecadal fluctuations in their distribution, abundance, and alternation, which are assumed to be linked with variations in the environment. The occurrence of this phenomena is known as Regime. Over the past 30 years, extensive research has been done to document these fluctuations. However, the geographical scale at which these variations occur and their implications are still not fully understood. Here, a methodological approach is proposed to 1) determine the geographical scale at which the occurrence of the Regime can be detected (Regime signature) within systems, 2) identify if the Regime signature is present in the many different small pelagics fisheries regions, on unique to eastern boundary currents and Japan, and 3) how the fishers incorporate the perception of fluctuations at different frequencies. For the first two, we propose using the "periods" method to detect dominant variability scales at local (ports) and full systems. For the third, the methodological approach is based on interviews with key actors in the US (California), Mexico (Gulf of California), and Chile (Humboldt). The results will be incorporated into a simple economic model to explore different savings schemes that could mitigate the collapses and facilitate the long term business viability.

S1-P15

Distribution shifts of capelin (*Mallotus villosus*) and arctic cod (*Boreogadus saida*) in the Northwest Atlantic and consequences for regional productivity

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Capelin (*Mallotus villosus*) and Arctic Cod (*Boreogadus saida*) are the two prominent prey species in the Northern Grand Banks and Labrador shelf ecoregions. Abundance and distribution of these species have changed markedly during the last 30 years, with the species exhibiting various degrees of overlap. Through an investigation of environment, diet, life history parameters and schooling attributes this study investigates potential drivers for these distribution changes and the consequences of distribution shifts or expansions to predators.

S1-P16 (Moved to Oral Section, S1, (March 10, 11:40)

Demographic connectivity of sardine in the Bay of Biscay and Iberian coast region

Alexandra **Silva**[1], Susana Garrido[1], Lionel Pawlowski[2], Isabel Riveiro[3], Fernando Ramos[4], Pablo Carrera[3], Vitor Marques[1], Erwan Duhamel[2], Leire Ibaibarriaga[5] and Andres Uriarte[6]

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Widely distributed species, such as sardine, are often structured in multiple regional populations connected by dispersal/advection of early life stages and migration/straying of juveniles and adults. Core regional populations of sardine are linked to hotspots of recruitment located in high productivity retention areas: northern and central Bay of Biscay, Northwestern Iberia and Gulf of Cadiz. Areas in-between, typically with lower abundance and predominance of older individuals, southern Portugal and the northern Spanish waters (Cantabrian Sea and North Galicia), appear to be sustained by straying from core areas. In the past 15 years, the Bay of Biscay population showed several strong recruitments whereas the population off Northwestern Iberia decreased severely due to prolonged low recruitment. This situation provided an opportunity to investigate the connectivity between populations and how it is affected by fish abundance and environmental conditions. To that purpose, we modelled the temporal and regional distribution of fourteen sardine cohorts using age and area-disaggregated data from acoustic surveys and catches. The results indicate the northern Spanish region has a stronger connectivity with Northwestern Iberia than with the Bay of Biscay. Strong cohorts recruiting off Northwestern Iberia dispersed to northern Spain during their first 2-3 years of life while dispersal from the Bay of Biscay to the south appeared to be negligible. The interplay between density and environmental conditions (SST and CHLa) on sardine dispersal is also examined.

S1-P17

Enhancing the pelagic fish catch in regions adjacent to ocean upwelling fisheries

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The major upwelling fisheries are sustained by the flow of organic material generated in the photic zone. These fisheries are presently managed so they are exploited at near their sustainable limit. It is assumed that the yearly average catch is controlled by the supply of primary production (bottom up control). Primary production can be estimated from satellite observations and compared with the reported fish catch for the three largest fisheries, Humboldt, Canary and Benguela regions. If additional nutrients were injected into the photic zone near the boundary of the region of high productivity, one would expect the small pelagic fish to colonise the fertilised region and if upwelling conditions could be mimicked, the empirical ratio of primary production to fish catch can be used to estimate the additional fish biomass produced. For steady injection of nutrients at a concentration typical of the adjacent upwelling, it is estimated addition of each 1 tonne of reactive nitrogen (and other required nutrients) might provide 250-400 kg of sustainable potential fish catch.

S1-P18

Spatial and temporal variability of the North Humboldt Current System upwelling front and its influence on small pelagic resources distribution

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Eastern Boundary Upwelling Systems (EBUS) are biologically productive marine regions covering less than 1% of the ocean area, but providing a significant amount of the world's capture fisheries. The high levels of productivity in the North Humboldt Current System (NHCS) result from a combination of large-scale to local factors.

The Peruvian anchovy ***Engraulis ringens*** is the most important species in the Peruvian sea due to its socio-economic impacts. The Peruvian anchovy inhabit the Peruvian coastal marine zone and limited by the upwelling front.

In this study we document the temporal and spatial variability of the upwelling front at seasonal and interannual frequency for the period 1981-2016 using AVHRR data. This information is complemented with high-resolution glider data and cross-shelf repetitive hydrographic sections to document the seasonal and ENSO modulation on the NHCS upwelling front.

The variability of the upwelling distribution in the coastal marine zone also causes changes in the distribution of the resource living there, mainly of Peruvian anchovy, a high environmental sensitive small pelagic fish. Time series of landings of anchovy has direct relation with oceanographic variables, in both large and short term, oscillation of periods of abundance or intraannual lowest landings. In addition, this warm water affects the biological characteristic of the resource, fat content, growth, reproduction and recruitment. This changes in the resource impacts directly to the fishery, and generate economic instability, mainly to people who depends of this extractive activity.

S1-P19

The sardine population in northwestern Mexico: Current state

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The Pacific sardine on the California Current showed a reduction in their fishery biomass and near disappearance of spawning grounds off California. A Moratorium on fishing was instituted in California for 2015-16 when estimated biomass dropped below 150,000 MT (roughly 144,000 MT) and continued into 2016-17 as the biomass continued to fall. The landings by the Ensenada fleet were generally increasing from 2004 through 2014 with an overall average less than 64,000 MT, the landings in 2015 dropped 35%. This reduction in biomass also occurred with displacements of sardines further from the traditional fishing grounds near Ensenada. The fishery-independent egg surveys to characterize the relative amounts of sardine spawning habitat in both Mexico and the U.S. during spring 2000-2013 showed an increased distribution of eggs and the size of the spawning area toward waters south of Punta Eugenia, reaching Bahía Magdalena. This southernmost distribution occurred with an increase in the total spawning fraction in waters of Mexico but contrasts with the one observed trend toward lower spawning observed in U.S. waters. These conditions associated with large-scale fluctuations in ocean conditions that result in favorable to unfavorable habitat for sardines caused increasing concern in the local industry and managers in Mexico due to increased fishing effort that has resulted in abrupt changes in availability of sardines and resulted in the deterioration and losses to the industry with the closing of a number of processing plants.

S1-P20

Categorizing ecological indicators for predicting Hilsa shad (*Tenualosa Ilisha*) abundance in northern Bay of Bengal

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Fisheries sector plays an important role in the Indian economy by contributing 1.1 % in national gross domestic product and by optimizing food security of the country. Presently around four million people are involved in the marine fishing sector and fish landing data shows that fisheries in India has dwindled spatially and temporally over the last few decades; possible reasons could be climate change and overexploitation. Under these alarming scenarios, understanding and categorizing climate, physical, biochemical ocean properties towards projecting marine fish production and catch potential are major challenges face by fisheries scientists and policymakers of developing countries where fisheries sector is not yet regulated. In this paper, we studied the phenomenon of an unusual bumper landing of Hilsa shad along the northeast coast of India during 2010. We place particular interest in the causes behind this bizarre event which is linked to fish migration by exploring a set of ecological indicators. We found that this shad species resides in the ocean during winter and spring, feeding on phytoplankton. However, adults stop feeding before spawning in the rivers/estuaries; the availability of optimum phytoplankton in the spawning ground is indispensible for larval rearing. Salinity reduction caused by rain-over-the-sea or by increase in river discharge triggers breeding migration and adult fish prefer to stay near ocean/river bed at such times. Further while anticipating the catch potential of 2016, the result demonstrate that precipitation has significant impact on successful breeding migration and using effective monsoon forecast, experimental anticipation of catch potential is plausible.

Keywords: Hilsa shad, migration, fishing, monsoon, anticipation, Bay of Bengal

S1-P21

Oceanographic conditions and spatial distribution, migration patterns and fishing grounds for saury, sardine and mackerels in the Northwest Pacific

Elena **Ustinova**, Dmitry Antonenko, Yury Novikov, Viktor Filatov, Alexander Zhigalin, Vitaly Dudarev and Alexander Starovoytov

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In this study, we analyzed the impact of oceanographic conditions on spatial distribution, migrations and the fishing grounds formation of saury (*Cololabis saira*), sardine (*Sardinops melanostictus*), and mackerels (*Scomber japonicus* and *Scomber australasicus*) in the Northwest Pacific. We used regional data sets based on surveys conducted by TINRO-Center's R/Vs (CTD, plankton net, pelagic trawl and acoustic surveys), materials obtained by scientific groups in the fisheries expeditions and remote sensing data. Key dynamic structures (branches and meanders of Kuroshio, Oyashio, Soya and Subarctic currents, and mesoscale eddies) and related oceanographic fronts affect the migration patterns of the fisheries species in many aspects. The important determining factor of the spatial distribution and fishing grounds for saury, sardine and mackerels saury is the presence and position of the large anticyclonic eddy east off Hokkaido Island in summer and autumn. This eddy influences the fishery during several months. The second critical factor is the anticyclonic eddy located east off Bussol Strait, but it was less steady. In June of 2014–2016, the main mackerel and sardine aggregations have been observed on the warmer water side in high-gradient zone of the North Subarctic Front. From July to August of 2015–2016, the maximum catches were recorded in the food-rich subarctic waters to the west from "third" Kuroshio branch. Higher concentrations of these species were observed in waters with SST ranged from 12°C to 18°C. In the last three years, transformed subtropical water to the east of 154°E spread farther north than usual. This situation was favorable for more intense northward migrations of sardine and mackerel.

S1-P22

Spatial patterns diversity of copepods under coastal upwelling variability off North West African ecosystem

Laila El Arraj[1], Omar **Ettahiri**[1], Laila Somoue[1], Mansour Serghini[1], Najib Charouki[1], Gabriella Bianchi[2] and Marek Ostrowski[3]

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The assessment of copepods distribution in relation to environmental factors "upwelling" between Cape Blanc (21°N) and Cape Bojador (26°N) was established. The study was run during two different seasons and covered an area of 6 transects along the south part of Moroccan Atlantic coast. The oceanographic cruises were carried out on board the R/V 'Fridjof Nansen' in November 2011(fall) and July 2012 (summer).

The overall total of mesozooplankton groups accounted was 19. Copepods constituted the highest fraction in all sampled layers during both investigated periods as they contributed at least 65% of the total mesozooplankton community.

A cluster analysis allowed the assessment of species assemblages and the projection of copepods species on T/S diagrams revealed that there was no clear pattern in densities variation over the seasons.

To describe the community structure in relation to hydrological parameters variability, a Multiple Analysis Factorial performed between dominant species densities and environmental factors has shown a positive correlation of most of species to chlorophyll'a' concentration during both seasons and were mostly represented by herbivorous species.

S1-P23 CANCELLED

Drivers of inter-anual variability in the abundance of the Broadband Anchovy *Anchoviella lepidentostole* in southeast Brazil

Santiago **Montealegre-Quijano**[1], Jocemar T. Mendonça[2] and Érico T. Teramoto[1]

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The Broadband anchovy, *Anchoviella lepidentostole*, is a traditional fishery resource in state of São Paulo, southeast Brazil. The species is caught by artisanal fishermen in the rainy and warm season from September to March (spring/summer), when dense shoals migrate upstream to spawn in the Ribeira-de-Iguape River. There are records of this activity dating back to early nineteenth century, but production data are scarce. About 5000 t were landed in 1938-1940, providing the raw material for about thirty fish processing industries along the river. Then, in 1970s, a peak of 4000 t was recorded, with about 500 fishermen in activity. Since then, production has decreased, and at present 1,800 fishermen catches about 800 t per year, of which, only one portion is sent to the single remaining industry. It is well known that changes in fish populations are primarily driven by *variability in recruitment.* However, we do not know yet which environmental variables are directly related to reproductive success, and therefore with high fishing yields. Thus, in this study we analyzed fishing data of catches and CPUE (kg/h), together with the environmental data of river flow rate, rainfall, continuous wet days, continuous dry days and frequency of rainy days, aiming to build a model that allows for production estimates under different scenarios. It was observed a positive relationship between river flow rate and catches obtained two years later. This gives clues about the effect of this variable on recruitment. The results are discussed with focus on co-management.

S1-P24, MOVED TO ORAL SECTION, MARCH 8, 12:00-12:20

Size structure based associations between anchoveta and other pelagic resources in Peruvian waters

Miguel **Ñiquen**, Marilu Bouchon, Andres Chipollini and Cecilia Peña

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The main interactions in the distribution and abundance of anchoveta (*Engraulis ringens*), sardine (*Sardinops sagax*), jack mackerel (*Trachurus murphyi*) and Pacific mackerel (*Scomber japonicus*) in Peruvian waters have been described, although most authors concentrate on the comparison or interactions of total biomasses or relative total abundance level without discriminating by fish size or age group. The data used in this work came from observers on board of vessels participating in the Peruvian purse-seine pelagic fisheries. Analysis of catch per set of the purse-seine fisheries between 1996 and 2007 shows that these species were caught in the same set having the same or similar size structure only in 1998. Three groups of sets were considered based on their catch species composition: a) sets with anchoveta only, the size distribution was unimodal around 14 cm total length; b) sets with both anchoveta and sardine, the distribution range of both was located between 10 and 20 cm, with a common modal size around 13 -14 cm; and, c) sets with only sardine, the size distribution was bimodal, with the main mode around 20 cm, with larger fish size offshore and smaller inshore. It was noted that in 2015 – 2016 a similar association by size was repeated between anchoveta and pacific mackerel. The two species were caught in the same set, with similar modal sizes between 14 and 16 cm, but once Pacific mackerel grows larger it separates from anchoveta and migrates farther offshore. We emphasize that the critical period of competition occurs between the adult stage of anchoveta with the juvenile stages of other pelagic species, mainly in the coastal zone. This type of interaction can play a key role influencing species abundance during the following years, and the persistence or increase of these associations could be an indicator of ongoing future changes in their dominance in the pelagic ecosystem.

S1-P25 CANCELLED

Evaluating spatial patterns in foraging landscapes and energetics: (part 2) modeling projections for pollock under future scenarios

Kirstin **Holsman**[1], Elizabeth Siddon[1], Kerim Aydin[1], Anne Hollowed[1], Jim Ianelli[1], Ron Heintz[1] and André Punt[2]

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Taxonomically disparate, non-linear relationships between physical conditions and marine species, ecosystem structure, and productivity portends dynamic and complex responses to climate-driven changes and variability in physical conditions, particularly in arctic and subarctic systems like the Eastern Bering Sea (AK). Because species differentially respond to changing conditions, shifting conditions have the potential to induce mismatch between predator and prey production rates. We used multiple future projections of physical conditions and lower trophic level productivity in the Eastern Bering Sea under a variety of future scenarios to evaluate the sensitivity of bioenergetic scope for growth of juvenile walleye pollock (*Gadus chalcogrammus)* to changes in physical conditions and lower trophodynamic processes. We found that potential growth is sensitive to spatial predictions and variability in future conditions; in some scenarios growth potential remained within historical ranges while in others shelf-wide warming led to marked reductions in future growth potential over the next 50-100 years due to suboptimal thermal conditions for pollock. Our work highlights the importance of continued studies that evaluate changes in growth potential and foraging hot-spots across the Bering sea. Please note that this abstract is complementary to *"Evaluating spatial patterns in foraging landscapes and energetics (part 1): empirical observations for pollock across a long-term time series from the eastern Bering Sea"***.**

S1-P26

Evaluating spatial patterns in foraging landscapes and energetics (part 1): Empirical observations for pollock across a long-term time series from the eastern Bering Sea

Elizabeth **Siddon**[1], Kirstin Holsman[2], Alex Andrews[1], Jordan Watson[1], Ed Farley[1], Ron Heintz[1] and Jim Ianelli[2]

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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 the extent and duration of winter and spring sea ice are the cornerstone of ecosystem-level responses ranging from phytoplankton to seabirds. 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*). A spatial match-mismatch has been qualitatively demonstrated for representative warm and cold years in the eastern Bering Sea to help explain recruitment variability across contrasting climate conditions. We build on that work, utilizing empirical observations between 2003-2016, and retrospectively develop an index of spatial overlap between juvenile pollock and foraging landscapes. This ecosystem indicator spans recent transitions between above- and below-average thermal conditions and integrates bottom-up influences (i.e., oceanographic conditions, prey resources) on fish growth and condition needed to relate environmental conditions to biological processes. We propose the index of spatial overlap forecasts cohort strength and recruitment success for Walleye pollock and demonstrates a mechanistic relationship that may be broadly applicable to pelagic fish populations worldwide. This work is complimentary to modeling efforts presented by Holsman et al. to project pollock recruitment under future scenarios.

Session 2
Poster Presentations

External drivers of change in early life history, growth and recruitment processes of small pelagic fish

S2-P1

Geographic and temporal variation in elemental composition of age-0 walleye pollock (*Gadus chalcogrammus*) otoliths in the western Gulf of Alaska, September 2007 and 2011

Matthew T. **Wilson**[1], Annette Dougherty, Mary Elizabeth Matta, Kathryn L. Mier and Jessica Miller

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Otolith chemistry can potentially be used to reveal juvenile-adult population connectivity and improve our understanding of recruitment processes and sub-stock structure of economically and ecologically important marine fishes. We focused on the initial step of demonstrating meaningful geographic variation in the chemistry of otoliths of age-0 juvenile walleye pollock in the western Gulf of Alaska (GOA). Study objectives were to first statistically test the hypothesis that otolith chemistry did not differ geographically among 3 hydrographic sub-regions and then to explore inherent geographic and temporal variation in the elements most responsible for hypothesis rejection. Laser ablation, inductively coupled plasma-mass spectrometry was used to measure 17 isotopes in 228 otoliths of fish collected by midwater trawling in the sub-regions during late-summer 2007 and 2011. The cold, saline Kodiak Island sub-region was distinguished from relatively warmer, fresher sub-regions due mostly to higher strontium:calcium and lower barium:calcium ratios. Otolith chemistry distinguished sub-region for 62% (2007) and 68% (2011) of the fish. Inherent geographic variation was largely consistent with our *a priori* sub-region delineation, which was based on the relative apparent influence of the Alaska Coastal Current (ACC) (warmer, fresher water) versus oceanic water (colder, saltier). Interestingly, fish in sub-regions most influenced by the ACC exhibited a pronounced and synchronous decline and recovery in strontium:calcium ratios prior to capture consistent with sporadic ACC-related freshening of the coastal environment. Thus, as will be discussed, otolith chemistry appears to have utility for studying potential habitat-related effects on the process of walleye pollock recruitment in the western GOA.

S2-P2 ALSO TALK on MARCH 8, 15:00-15:20

Herring research and monitoring in Prince William Sound, Alaska

W. Scott **Pegau**[1], Rob Bochenek[2], Kevin Boswell[3], Trevor Branch[4], Kristen Gorman[1], Ron Heintz[5], Paul Hershberger[6], Hayley Hoover[1], Steve Moffitt[7], Pete Rand[1], Fletcher Sewall[5], Richard Thorne[1], Johanna Vollenweider[5] and Sharon Wilde[5]

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The Pacific herring population in Prince William Sound (PWS) collapsed shortly after the *Exxon Valdez* oil spill (EVOS). Since that event in 1989 the EVOS Trustee Council has funded considerable research on herring. Beginning in 2009 they chose to fund research through integrated programs. In 2012 the Herring Research and Monitoring program began. The program includes nearly 20 projects aimed at improving predictive models of herring stocks through observations and research. The program contains a mix of process and monitoring studies, with an emphasis on research related to overwintering survival in the first year of life. We have found correlations between early growth and environmental conditions, differences in energetics within PWS, movements of tagged herring, genetic separation with other nearby herring populations, along with other advancements. A general overview of the program, a highlight of results, and a brief description of future efforts will be provided.

S2-P3

Effects of density dependence in growth and condition factor on pre-recruit chub mackerel *Scomber japonicus*

Yasuhiro **Kamimura**, Chikako Watanabe, Ryuji Yukami and Sho Furuichi

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Chub mackerel, *Scomber japonicus*, is one of the most important fisheries resources in the western North Pacific. The Pacific stock of chub mackerel mainly spawn in April to June in the coastal waters around the Izu Islands off central Japan. Eggs and larvae are transported by the Kuroshio and Kuroshio Extension currents. The larvae and early juveniles are widely distributed in the Kuroshio–Oyashio transition region. Large juveniles migrate to the subarctic Oyashio area in August, and then fish about six months old recruit to fishery in the coastal waters off northern Japan. A previous study reported that higher growth rates in larval and early juvenile stages correlated with higher recruitment for chub mackerel. However, strong year classes often cause negative density-dependent influences on growth for many fish species. In the present study, mean daily growth rates and condition factor (CF) were analyzed using pre-recruit individuals collected in the Oyashio area from 2006 to 2013 in order to examine relationship between year-class strength and growth rates. Recruitment fluctuated between 435 (2006) and 6324 (2013) million age-0 fish. Mean daily growth rates from hatch to collection estimated by otolith analysis and CF at collection were significantly lower in the year classes of higher recruitment. Therefore, it is likely that higher growth in larval and early juvenile stages led to higher survival, but lower growth and CF after early juvenile stages through density-dependent processes.

S2-P4

Bioenergetics of European sardine: Simulating environmental influences on population dynamics in the western Mediterranean Sea

Marta **Albo-Puigserver**[1], Heidi Pethybridge[2], Joan Navarro[3], Isabel Palomera[1], Magdalena Iglesias[4], Andrés Ospina-Alvarez[5], Ana Ventero[4] and Marta Coll[1]

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5 Center for Marine Conservation, Biological Sciences Faculty, Pontificia Universidad Católica de Chile, Santiago, Chile

In the Mediterranean Sea, European sardine (*Sardina pilchardus*) is an important species in terms of biomass and catches, although recent declines have been observed, in addition to negative changes in body condition. The objective of this study was to better understand how sardine respond to environmental changes in the western Mediterranean Sea. We implemented a size-structured bioenergetics model based on Dynamic Energy Budget (DEB) theory. DEB models allow the description of the energy allocation in various physiological processes during organisms' full life-cycle (growth, maintenance, and maturity/reproduction from egg to adult). To calibrate the model biometric data collected from 2009 to 2015 and energy density estimates from calorimetry analysis were used. Model simulations captured ontogenetic growth patterns and energy storage in spring and summer previous to the spawning season. To examine population dynamics, the DEB model was coupled to an individual-based population model. Scenarios of increasing sea surface temperature (SST) and reduction of food availability (FA) were tested. Stock productivity of sardine was affected through reductions of individual growth rates with decreasing FA, as well as reductions in fecundity rates due to a shorter spawning window as a consequence of an increase of SST in the study area. This information will be vital in assisting the management plans of sardines in the Mediterranean marine ecosystems in the near future.

S2-P5

Empirically-based models of oceanographic and biological influences on Pacific herring recruitment in Prince William Sound

Fletcher **Sewall**[1,2], Brenda Norcrossb[2], Franz Mueter[2] and Ron Heintz[1]

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Small pelagic fish abundances can change dramatically over time and are difficult to forecast, partially due to variable numbers of fish that annually mature and recruit to the spawning population. Recruitment strength of age-3 herring in Prince William Sound has been estimated by managers as a function of spawning stock biomass via a Ricker spawner-recruit model. However, stock size has little influence on subsequent numbers of recruits. This study evaluates the usefulness of herring recruitment models that incorporate oceanographic and ecological variables. Results indicate herring recruitment estimates may be significantly improved by modifying the standard Ricker model to include an index of young-of-the-year Walleye Pollock (*Gadus chalcogrammus*) abundance. We suggest that synchrony of juvenile herring and pollock survival may be caused by trends in abundance of their shared zooplankton prey, or high juvenile pollock abundance may promote prey switching and satiation of their shared predators. Including sea surface temperature, primary productivity, and additional predator or competitor abundances did not improve model performance. Identifying and monitoring factors that determine juvenile herring survival remain challenging, but the association between pollock and herring reported here represents a significant step forward in understanding herring recruitment.

S2-P6

Inter-annual variability in early life growth of the Bali sardine, *Sardinella lemuru*, caught off the northern Zamboanga Peninsula and the role of environmental factors

Alexanra A. **Bagarinao** and Wilfredo L. Campos

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Understanding the factors that strongly influence early life growth and subsequent recruitment is vital to predicting favorable and unfavorable conditions for population persistence and resilience. Otolith increments were examined to estimate growth rates of early stages of *Sardinella lemuru* from a 2-yr time period (2011-12 and 2012-13 spawning season), with fish collected from December to May at the same location off northern Zamboanga Peninsula. Based on the fitted regression, relatively lower growth rate was estimated for individuals hatched during 2011-12 season (0.76mm/day) compared to individuals hatched during 2012-13 season (0.90mm/day). However, growth patterns within spawning seasons were consistent with individuals hatched in middle of the spawning season (January 2012 & 2013) showing faster growth during the larval and early juvenile stages than those hatched early (Sep-Dec 2011&12) and late in the season (Feb-Mar 2012&13). This trend was observed in close association with high overall *chl a* (~food) concentrations in the area for the 2011-12 season (R=0.81) but wasn't observed for the 2012-13 season (R=0.34). Growth may vary as a function of environmental conditions. Due to high year-round temperature with relatively little seasonal differences in the tropics, it has been suggested that food, rather than temperature, is the major factor in determining early growth of tropical fish. However, results show that temporal variations in growth rate are not attributable solely to fluctuations in food abundance.

S

S2-P7

Testing the growth-survival relationship in the anchovy (*Engraulis ringens*) in northern Chile

Francisco **Cerna**[1] and Guido Plaza[2]

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The growth of fish in early stage is critical for survival and subsequent recruitment of marine pelagic fishes, because by growing faster individuals will reach larger sizes at any age enhancing their probability of survival in comparison with smaller individual of the same age. Recent studies have reported a very fast growth during the larval and juvenile stages of the anchovy *Engraulis ringens* along the Humboldt Current System. Under this new scenario it would be very important to test if early growth is related to survival in this species. In the present study this relationship was evaluated by comparing increment width and radii-at age between original populations with survivors collected at later stages. The increment width and radii at age through the two months of life were wider and larger in the survivor than in individuals from the original population in cohorts from the recruitment season of 2014. These results demonstrated that the bigger-is-better and growth rate mechanisms were operating in this species. In a second approach the relationship between early growth and indices of year class-strength obtained from stock assessment of anchovy was evaluated. The relationship between total stock biomass and abundance from hydroacoustic surveys showed the same tendency across years, and both indices showed a direct relationship with early growth of juvenile cohorts spawned in the previous seasons.

S2-P8

Modeling the transport of eggs and larvae of anchoveta (*Engraulis ringens*) during the spawning season in the inland sea of Chiloé, Northern Patagonia

Samuel **Soto**[1,2], Freddy Hernández[1,3], Iván Pérez-Santos[1,5], Carolina Parada[4] and Leonardo Castro[1,2]

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The early life stages of *Engraulis ringens* observed in the inland sea of Chiloé, northern Patagonia (41° to 47°S) vary in distribution and abundance during the reproductive season (October to November). These fluctuations are probably associated with environmental changes within the two adjacent basins of marked differences in oceanographic conditions where anchoveta spawn in northern Patagonia, which are believed to affect the transport and retention of eggs and larvae. The objective of this study is to describe the dynamics of transport (connectivity-retention) of the early stages of anchoveta in the inland sea of Chiloe during the reproductive period. To assess the changes in spatial/temporal distribution of eggs and larvae in this area, biophysical modeling was utilized coupling ROMS (Regional Ocean Model System) and IBMs models (Individual Based Models). The output physical variables from ROMS were spatially similar to those obtained from satellite images. Sea surface temperature patterns from the model and from satellite products reached high correlation coefficients (> 0.9-1.0). Biophysical model simulations, regarding the distribution of anchoveta during the reproductive period, adequately represented the dynamics of transport of the early stages. The transport had a south-northward direction, a strong connectivity occurred from the southern basin (Gulf of Corcovado and Boca del Guafo) to the northern basin (Reloncavi Sound and Gulf of Ancud), and, a significant retention occurred within the northern basin. The information by this mean generated can be utilized in management and conservation of this fisheries resource in the area (e.g. Marine Protected Areas).

S2-P9

Distribution of European anchovy, *Engraulis encrasicolus,* eggs and larvae in relation to environmental conditions in the south-western Adriatic Sea

Sara **Malavolti**[1,2], Andrea De Felice[1], Ilaria Costantini[1], Ilaria Biagiotti[1], Giovanni Canduci[1], Federica Grilli[1], Mauro Marini[1], Valentina Tirelli[3], Diego Borme[3] and Iole Leonori[1]

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Identification of possible spawning and nursery areas in relation to environmental conditions of European anchovy (*Engraulis encrasicolus)* is challenging from both ecological and management point of view because of the role in the food chain and the economic importance of this species. Eggs and larvae occurrence from ichthyoplankton survey (2012-2015) were examined to understand the mechanism that control their distribution in the south western Adriatic Sea. The aim of the present work was to find relations between both, eggs and larvae, of European anchovy with environmental and biological variables.

The egg and larvae densities varied through the years, with 2012 showing the highest values (39.49 eggs/m^2 and 52.78 larvae/m^2), while 2014 showed the lowest density values (20.51 eggs/m^2 and 24.46 larvae/m^2).

Quotient value analysis indicated the eggs habitat preference for salinity (38.6-38.99 PSU), temperature (25-26.47°C), bottom depth (49-139.5 m) and density of zooplankton (399-590.2 mg/m^2). Different ranges of habitat preferences were observed for total larvae (yolk sac plus larvae) concerning salinity (36.24-38.19 PSU) and density of zooplankton (590.3-5423.2 mg/m^2), while temperature and bottom depth were shared with eggs.

On the other hand, the Spearman's Rank correlations always showed positive relations between both eggs and larvae with zooplankton ($\rho = 0.240$, $\rho = 0.341$, $p < 0.001$). These findings suggest that the distribution of eggs and larvae in the south-western Adriatic Sea are mainly based on food availability when certain environmental conditions are met, and as such, this area can be considered as a good spawning and nursery area.

S2-P10

Environmental conditions for anchovy and common sardine recruitment in central-southern Chile (33°-40°S) between 1987 and 2013

Jorge **Castillo**, Alvaro Saavedra, Carolina Lang and Víctor Catasti

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Anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) are important components of the artisanal fishery in central-southern Chile. These species spawn mainly in winter-spring; sardine present a shorter spawning period focused in August while anchovy spawning season extends to December or January. Sardine recruitment occurs from late spring to mid-summer, and in the case of anchovy extending to autumn. The ratio of species composition in the biomass estimates and the captures has changed over the last 15 years. Contributions for each species have fluctuated between 60 and 40% until 2003, however since 2004 a notorious increase was observed in sardine which reached over 85% of the catch and biomass, and anchovy presented an important decrease. In this study we explore the functional relationships between the recruitment abundances obtained from acoustic cruises in summer and autumn and the physical oceanographic conditions (T°, S, O_2, Clo-a), turbulence indices, upwelling indices, and egg indices during winter and summer. The oceanographic data analyzed were collected in acoustic-oceanographic cruises carried out in winter, summer, and autumn between 1987 and 2013, while the acoustic recruitment biomass of anchovy and sardine were obtained in summer and autumn.

S2-P11 CANCELLED

The interannual and intraseasonal variability of Lagrangian transport in the southern Benguela

Moagabo Natalie **Ragoasha**[1,2,3], Steven Herbette[2] , Gildas Cambon[1], Claude Roy[1], Chris Reason[3] and Christophe Lett[4]

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This study analyses the physical mechanisms that impact on Lagrangian transport in the southern Benguela upwelling system, an environment in which currents are key components of many important ecological processes, including the dispersal of marine larvae. Our study wishes to disentangle the combined roles of mesoscale turbulence, highly present in the region, and of short-period (less than 10 days) wind variability.

A validated interannual simulation of the region, using ROMS, over the period 1990-2010, provides the mean dispersal patterns. The aim is to diagnose the interannual variability and intraseasonal variability of particles reaching the region offshore of Santa Helena (target region). Results highlight the contribution of high frequency atmospheric forcing on the variability of larval transport from the south coast to the west coast of South Africa.

S2-P12

Modeling effects of weight and growth rate on the recruitment variability of Pacific saury (*Cololabis saira*)

Hitomi **Oyaizu**[1], Satoshi Suyama[2], Shin-ichi Ito[1], Daisuke Ambe[3], Michio J. Kishi[4] and Sachihiko Itoh[1]

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4 Hokkaido University, Sapporo, Japan

We examine the recruitment variability of Pacific saury (*Cololabis saira*), which is a commercially and ecologically important pelagic fish in the North Pacific, using an individual-based model combining a bioenergetics model and migration model. We parameterize the mortality rate with the length, weight, condition factor, growth rate and temperature. The annual survival rates calculated by the model are compared with recruitment per spawning biomass (RPS) derived from the stock assessment for 2002–2015. The RPS is well reproduced in the model, especially in cases parameterizing the mortality using the weight and growth rate. Temperature also causes variability in the survival rates, but mostly the indirect effect through the growth rate, instead of the direct effect on the mortality. In the presentation, we will show the contribution of winter-, spring- and autumn-spawned cohorts to the variability in the total stock abundance, and discuss their differences in the recruitment processes.

S2-P13

Comparison of muscle and scale isotope signatures of Pacific herring (*Clupea pallasii*), and their application in regional life history studies in British Columbia (Canada)

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Carbon and nitrogen naturally occur in two stable isotopic forms. These isotopes are taken up by primary producers in a food web in ratios that reflect the interacting effects of temperature, elemental availability (e.g. nutrient concentrations), and productivity levels, among other factors. Subsequently, the baseline primary producer isotope ratio is transferred through the food web and transformed with largely predictable increases between trophic levels. The Carbon ($\delta^{13}C$) and Nitrogen ($\delta^{15}N$) stable isotope ratios of an organism's tissues therefore provide a powerful source of information on the environmental and food web conditions experienced by that organism. Here we present the results of a study comparing muscle and scale $\delta^{13}C$ and $\delta^{15}N$ of Pacific herring collected from nine different regions in British Columbia (BC) in 2014. Scale $\delta^{15}N$ values were on average ~ 0.9 ‰ lower than muscle values, providing a correction factor for the application of scales in isotope studies of herring feeding biology. Regional stable isotope signatures of adult herring largely overlapped, with the exception of fish collected in northern BC, suggesting a latitudinal difference in feeding conditions experienced by herring on the BC coast. Comparison of adult and juvenile herring isotope signatures for two stocks, which had similar adult signatures, found that juveniles differed significantly in feeding experience. This points to feeding conditions in herring nursery grounds as a possible key factor in long term stock trajectories.

S2-P14

Reconsidering evidence for the optimal environmental window in the southern Benguela

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Future climate change is expected to impact upwelling intensity in a manner that varies with latitude, and the ecosystem consequences of such a strengthening or a weakening of upwelling are dependent on physical and biogeochemical processes including nutrient supply, turbulence, and cross-shelf advection. The concept of an "optimal environmental window" (OEW) was originally proposed by Cury and Roy (1989) to describe upwelling conditions favorable for recruitment of coastal pelagic fishes. The OEW hypothesis suggests that production of plankton and fish are limited by nutrient supply during periods of low upwelling, while during periods of intense winds and high upwelling, production may be limited by increased offshore advection, disaggregation of prey layers associated with turbulence, or reduced primary production in response to light limitation. During periods of moderate upwelling, conditions are hypothesized to be most conducive for recruitment. Several subsequent studies of eastern boundary current upwelling regions have supported the OEW hypothesis. Here, we use a generalized additive modeling approach to explore the OEW and its relevance to small pelagic fish recruitment in the southern Benguela region using recently developed upwelling indices. Initial results suggest that anchovy recruitment is positively associated with upwelling intensity, while recruitment of sardines demonstrates no clear relationship to upwelling intensity. With respect to productivity of small pelagic fishes, limited support for the OEW hypothesis was found in the southern Benguela ecosystem. We intend to compare these results with those derived from other mid-latitude eastern boundary current upwelling ecosystems.

S2-P15 CANCELLED

Reproduction, age and condition factor (K) of *Sardina pilchardus* (Walbaum, 1792) in the Atlantic Moroccan

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Reproduction in Moroccan sardine is cyclical with potential interannual variations in its duration and its release date. The maximum release period could travel between November and March. The extent and timing of spawning depend on different groups of size / age succeeding in Moroccan fisheries. It appears that each group involved in reproduction in a different way depending on the period and the year considered. From the age of two years, sardines can reproduce on average throughout the year. Large spawners are probably responsible for the beginning and end of the reproductive cycle for the entire population. Young spawners usually lay after the great and have a short spawning season. The size at first sexual maturity (L_{50}) varies annually between 12.6 and 13.18 cm for females. The average fecundity rate is 29445 (± 3383) oocytes for a medium-sized female 20.5 (± 0.76) cm and an average somatic weight of 72.63 (± 7.81) g. The reproduction period is preceded by high values of the condition factor K. This implies an accumulation of reserves in the sardine before the breeding season.

S2-P16

Population dynamics of Devis' anchovy, *Encrasicholina devisi* (Whitley, 1940) in Pitas Waters of Marudu Bay, Sabah, Malaysia

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An investigation on population dynamics of Devis' anchovy, *Encrasicholina devisi* in the Pitas waters of Marudu Bay, Sabah, Malaysia was carried out from October 2012 to September 2013. The relationship between length and weight of *E. devisi* was established as $W= 0.0029TL^{3.418}$ or Log W = 3.418 Log TL – 2.533 ($r^2 = 0.98$). Monthly length frequency data of *E. devisi* were analyzed by FiSAT software to evaluate the different mortality rates and its exploitation level. The asymptotic length ($L\infty$), and growth co-efficient (K) were estimated at 9.45 cm and 1.50 yr^{-1}, respectively. The growth performance index (φ') was calculated as 2.127. Total mortality (Z), natural mortality (M) and fishing mortality (F) was calculated at 6.38 yr^{-1}, 3.32 yr^{-1} and 3.06 yr^{-1} respectively. The exploitation level (E) of *E. devisi* was calculated at 0.48. The exploitation level was below the optimum level of exploitation (E = 0.50).Therefore, in the Pitas waters of Marudu Bay, Sabah, the stock of *E. devisi* was found to be slightly under exploited.

S2-P17

A re-evaluation of the drivers of recruitment variability in capelin (*Mallotus villosus*)

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Capelin (*Mallotus villosus*) is a small forage fish that plays a key role in the transfer of energy from secondary producers to vertebrate predators in boreal food webs. Capelin are short-lived, and poor year-classes are recruited into the population within a couple years and can have a large effect on population biomass. Profound changes in abundance and distribution of capelin occurred in 1991 in Newfoundland (NL), which corresponded with the collapse of the groundfish stocks, and capelin biomass has yet to return to pre-1991 levels. In NL, where capelin spawn at both beach and demersal sites, recruitment is thought to be set early in the larval stage. Research in the 1970s and 1980s found that larval survival in the first two weeks, as the larvae emerge from the beach, was related to onshore winds. However, there has not been a re-evaluation of the drivers of capelin recruitment variability since the population collapse in 1991. Data, including densities and distributions, on emergent larvae (1990-present), 0-age (2002-present), and 2-age (1991-1992, 1996, 1999-present) capelin are collected annually by Fisheries and Oceans Canada. I re-evaluated the link between timing of larval emergence, onshore winds, and recruitment strength from 1990-2012 and found that the timing of onshore winds was not a driver of recruitment variability. Consequently, I am using this extensive time-series of emergent larvae, 0-age, and 2-age densities to explore which life-stage is the bottle-neck for survival and to identify the environmental (wind, temperature, salinity) and/or biological (prey availability, predation) drivers of recruitment variability in capelin.

Session 3
Poster Presentations

The role of small pelagic fish in food web dynamics between plankton and top predators

S3-P1

Food web changes in epipelagic nektonic communities of the Northwest Pacific Ocean

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The trophic structure of the epipelagic nekton communities has been studied in two areas of the Northwest Pacific: in waters off the Kuril Islands and Eastern Kamchatka in June–July of 2004–2016, and in the central and western parts of the Subarctic Current zone and adjacent waters in February–April of 2009–2011.

In waters off the Kuril Islands and Kamchatka, we observed not only inter-annual variability of the nekton community composition, but also continuous changes in the abundance and composition of upper trophic levels during summer season within the entire surveyed area and in its different parts. The most significant variations were detected in 2014–2016 due to the high abundance of sub-tropical migrants. As new elements were involved in the food web, relative production and energy transfer pathways from low to upper trophic levels have changed. First of all, this was linked to copepods, and then to euphausiids, amphipods and small-sized nekton. There were no significant inter-annual changes in energy flows in the central and western parts of the Subarctic Current zone in winter.

Based on the estimates of daily and seasonal energy flow from low to upper trophic levels, nekton biomasses in the 2000s, and the nekton grazing impact on zooplankton, we concluded that there was no over-pressure on prey resources in the epipelagic layer throughout the research area.

S3-P2

Zooplankton Mean Size and Total Stock (MSTS) indicator applied for testing the feeding conditions of small pelagic fish in the southern Baltic Sea

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Results on mesozooplankton community structure dynamics provide valuable information on understanding of ecosystem functioning, changes in pelagic food webs, and contribute to the assessment of Good Environmental Status as defined in the EU Marine Strategy Framework Directive (MSFD).

The zooplankton Mean Size and Total Stock (MSTS) is a Baltic Marine Environment Protection Commission (HELCOM) core indicator primarily relevant for food webs (MSFD criterion 4.3: abundance/distribution of key trophic groups/species) with secondary link to biodiversity (MSFD criterion 1.6: habitat condition). MSTS indicates that the investigated pelagic food web structure is or is not optimal for energy transfer from primary producers to fish.

MSTS indicator appears to be very useful for testing of the temporal dynamics in the pelagic food web structure in the southern Baltic Sea. It considers the zooplankton mean size change as a consequence of an increase of small taxa biomass (along with an increasing eutrophication) and especially a decrease in abundance of larger copepods (due to the impact of hydrological conditions' change as well as predatory pressure of small pelagic fish). MSTS indicator provides estimates of the feeding conditions for sprat and herring in terms not only of food availability but its appropriate quality as well.

Presented data are the Polish contribution to the HELCOM COMBINE Programme. In most of the cases, samples were taken 5 times per year using the WP-2 net and the longest data series started in 1979.

S3-P3

Diel variability of the diet of *Sardina pilchardus* larvae in Málaga Bay (Alboran Sea, SW Mediterranean)

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The most common small pelagic fish species in Málaga Bay (SW Mediterranean Sea) is the sardine (Sardina pilchardus). Despite its commercial importance in the region, little is known about the ecology of their early life stages and their role in the trophic web dynamics. However, the importance of copepods and phytoplankton in the diet of sardine larvae in productive regions of the Mediterranean Sea and Iberian Atlantic littoral has been recognized. Here we present the results of a 26 hours survey during which we followed a shoal of sardine larvae (ranging 6 - 18 mm standard length) and the associated planktonic community in the northern Alboran Sea. We analyzed morphologically the diel variability of the micro- and mesoplankton community composition, as well as the diet of the sardine larvae by means of molecular tools (multiplex PCR assay). We observed day-night variations both in the plankton abundances and larval gut fullness. When comparing the food available with the ingested items detected by PCR, we found that sardine larvae preyed on the most abundant copepod species, suggesting an opportunistic predator behavior rather than a selective one. This work was funded by the Andalucian Government through project MOLDIALB (P11-RMN-7354).

S3-P4

Colonizing new habitats and meeting new neighbors: Trophic relationships between the expanding round sardinella and coexisting small pelagic fish in the NW Mediterranean Sea

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Climate change is a main driver of the species expansions outside their native range. The arrival of new species may have important effects on ecosystems, affecting native species and communities. The recent northward expansion of the round sardinella *Sardinella aurita* in the Mediterranean Sea, has been documented as a consequence of water temperature increase. This expansion provides an excellent field-laboratory opportunity to investigate (1) the trophic strategies of marine species in expansion and (2) the trophic impact of this new species on ecological similar native species. Here we combined isotopic and stomach content analyses to investigate the trophic habits of round sardinella and the trophic relationships with coexisting pelagic fish species, in the NW Mediterranean Sea. Results revealed changes in the diet of round sardinella during the year. In summer, the most important preys were copepods (*Acartia* spp.) and cladocerans (*Penilia avirostris*). During autumn and winter, the diet was composed mainly by copepods and cirripeds. Surprisingly, during spring round sardinella mainly feed on salps (Thaliacea). This is the first study identifying salps as important prey in sardinella diet. When comparing trophic habits with coexisting pelagic fish, we found that round sardinella adults have a different trophic niche from European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*). In contrast, round sardinella juveniles partially overlap with these species. These results provide new insights to understand the ecological role of the expanding round sardinella in the Mediterranean Sea.

S3-P5

Function of the small pelagic fishes in the marine food web dynamics of the Beibu Gulf, South China Sea

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As an important international fishing ground for both of China and Vietnam, the Beibu Gulf (formerly name Gulf of Tonkin, locating in the north-western South China Sea) has abundant fisheries resources and tropical-subtropical biodiversity. However, the fisheries resources structure, biodiversity and ecosystem services have depleted since the fishing and other anthropogenic activities increased from 1980s. Combined with the former random sampling and on-spot survey data, an annual investigation of four seasons were carried out between August 2010 to May 2011 to understand the process of small pelagic fish (SPF) resources dynamics, the species composition and spatio-temporal distribution pattern. Both of the survey and remote sensing environmental data were used to reveal the development principal of the pattern. Stomach content and carbon and nitrogen stable isotope analysis were used to determine dominant species' feeding habits and trophic levels. Ecosystem trophic structures were constructed with the EcoTroph model. According to the fish community structure and function, *Decapterus maruadsi*, *Sardinella aurita* and *Stolephorus zollingeri* were identified as the key SPF species through energy flow channel analysis. Moreover, the impacts of SPF on marine ecosystem sustainable development were assessed. This study aimed to understand the functions of SPF on marine ecosystem stable development and contributed to biological resources sustainable exploitation strategic decision-making.

S3-P6

Temperature and size-dependent functional response of *Sprattus sprattus* L.

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Functional response (per capita feeding rate as a function of prey concentration) is an essential component in larger ecosystem models to describe predator prey interactions. Despite its prominent ecological role in the Baltic Sea food web and various ecosystem modeling studies performed in the past, the effect of temperature and fish size on feeding rate of sprat is unknown. In contrast to most other clupeids, sprat is known as an exclusive particulate feeder from post larval stage on, showing no filter feeding even at highest prey concentrations. Here, we performed a comprehensive experimental study to quantify the size- and temperature-dependent functional response. Feeding rates were estimated by under-water video observations for different size groups of fish with means ranging from 3.6 to 8.7 cm total length at different temperatures (5 to 20°C). Non-evasive ***A. salina*** nauplii were used as prey starting each trial with high concentrations (330 L-1) to estimate the physiologically possible maximum feeding rate of sprat. The size-related parameter of feeding rate of larger sprat (> 9cm TL) was estimated by a stomach content evacuation model using field data. Sprat showed a functional response type II for all body sizes and temperatures. Feeding rate clearly increased with increasing body size and temperature ($Q10 \approx 1.5$) and reached a maximum biting rate of about 2.0 s^{-1}. Analyses of sprat stomach content from experiments and field revealed high individual variability of feeding activity.

S3-P7

Ecosystem modeling in the western North Pacific with a focus on small pelagic fish

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Small pelagic fish such as sardine, anchovy and mackerels are commercially and ecologically important in the western North Pacific. An ecosystem model in the area with a focus on these species is constructed using a static mass balance model, "Ecopath" as an initial step to evaluate their role in the ecosystem. A total of 37 functional group is considered in this exercise. The area is divided into three geographical blocks considering bottom topography and oceanography: coastal Oyashio, coastal Kuroshio and offshore. It is assumed that some species are endemic to a block (e.g. bottom fish) while migrating species (e.g. small pelagic fish) are distributed in two or three blocks. The blocks are connected by small pelagic fish because they migrate among blocks. The coastal blocks are corresponding to the areas where offshore trawl fisheries are conducted. A reasonable mass balanced model is obtained after evaluation of quality of input data (pedigree) and pre-balance (PREBAL) diagnostics. An ecosystem network analysis indicator, mixed trophic impact (MTI), indicates that changes in biomass of small pelagic fish impact most of groups from low to high trophic levels. The constructed model will be expanded to a time-dynamic model using Ecosim to test possible fisheries management scenarios considering complexity of the ecosystem.

S3-P8

Jellyfish blooms in warm water may signal trouble for forage fish in a warming climate

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Forage fish are key to marine ecosystems because they readily pass energy between lower and upper trophic levels. Gelatinous zooplankton (i.e., carnivorous medusae, ctenophores, pelagic gastropods, salps; hereafter "jellyfish"), on the other hand, are undesirable to most marine predators and therefore may represent a trophic dead end in the pelagic food web. High dietary overlap between jellyfish and forage fish promotes competition where they co-occur and food is limited, and some evidence suggests there is a negative relationship between these pelagic taxa. We conducted hydroacoustic-trawl surveys of forage fish in Prince William Sound during summers of 2014 – 2016. Preliminary results indicate that compared to other years, there was a large influx of jellyfish throughout the water column in 2015 and coincident with low densities of young of the year (YOY) walleye pollock. In 2016 jellyfish densities were still higher than in 2014, but they were largely confined to the upper water column above the depth at which we observed large inshore aggregations of YOY pollock. Although trawl data suggest jellyfish and YOY pollock often co-occur, hydroacoustic data show a separation between the highest densities of these taxa. Jellyfish may respond positively to warming conditions, which could increase competition for food resources important to YOY pollock and other forage fish species in the future. Efforts to unravel the consequences of recent anomalous ocean conditions on marine ecosystems may benefit from a closer look at jellyfish and forage fish interactions.

S3-P9

Humpback whales ruin a perfectly good overwintering strategy for Pacific herring in Alaska

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The strategy of Pacific herring (*Clupea pallasii*) to form large overwintering shoals, that are spatially and temporally predictable, seems counterintuitive when faced with predation from humpback whales (*Megaptera novaeangliae*). We monitored the decline and abandonment of two herring overwintering areas in Prince William Sound, Alaska, that have recently experienced a period of intense whale predation. These declines contrasted with herring in Lynn Canal, where predation by whales was less intense and overwintering herring shoals have persisted for at least 40 years in the same location. We present an argument that overwintering in relatively shallow bays and fjords was a successful means of reducing predation risk from the predominate mesopredators (pinnipeds, birds, and demersal fish) when whale populations were depleted due to commercial harvest, but may be maladaptive under intense pressure from a recovered humpback whale population. Our observations indicate that herring overwintering strategies in the Gulf of Alaska may be in a state of transition in response to whale predation. It is unknown if the herring missing from the Prince William Sound overwintering grounds have moved to new areas or been consumed by whales or other predators. This population was depleted prior to intense exploitation by whales. The return of humpback whales as significant predators to the North Pacific will have both direct and indirect impacts on their prey. Successful management of these herring populations for commercial harvest will require consideration and understanding of humpback whale foraging behavior.

S3-P10

The role of small pelagic fish in the western Iberian upwelling ecosystem

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This work describes the trophic structure and function of the western Iberian continental shelf ecosystem using the Ecopath mass-balance model. The model considers 33 functional groups spanning trophic levels from phytoplankton to top predators and the fisheries but focus on the pelagic component of the ecosystem. The results indicate that in the period 2006 – 2009, sardine was the dominant species of the ecosystem due to a high relative biomass, high trophic connectance and high impact in other functional groups. Sardine represented 16.3% of consumers' biomass and consumed 21.1% and 0.36% of the total biomass produced by meso- and micro-zooplankton and phytoplankton, respectively. 23% of sardine production was taken by the fisheries and 72% was consumed by 19 of the 30 consumer functional groups. Fish (31.5%) and cephalopods (30.9%) were the main predators. Top predators such as marine mammals (9.4%) and especially seabirds (1%) showed comparatively low levels of consumption although some of the species showed preference for sardine. Moreover, sardine had the highest overall impact in the ecosystem of all functional groups. An increase in sardine biomass showed both positive and negative impacts, either direct or indirect, on its predators and prey. These findings support the hypothesis of a wasp-waist structure of the ecosystem, with sardine as the main link. However, functioning as a "waist" may be temporary given the rapid changes in the abundance of small pelagic fish in this type of ecosystem.

S3-P11

Seasonal variation of Omega-3 content from Bali Sardines catch in Bali Strait and its drivers

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Bali Sardines, *Sardinella lemuru* (1853), are known as one of the high nutritional sources of fishes rich of omega-3 fatty acids. Their distribution is highly related with the physic-chemical characteristics of the oceans. Changes in the oceanographic parameters might have significant effects on the content of the omega-3. This study observed the distribution of Bali Sardines based on the monsoonal seasons and also examined the relationship between the environmental factors including feeding behavior and omega-3 content. Omega-3 content was analyzed from the catches of Bali Sardines during four different periods of monsoonal season in Bali Strait, Indonesia. The results showed an inverse relationship of stomach content of Bali Sardines between phytoplankton and zooplankton. High content of phytoplankton was followed with low content of zooplankton in the stomach content of Bali Sardines and it occurred in November 2012 during the inter-monsoon season. On the other hand, high content of zooplankton and low phytoplankton was found in February 2013 during Northwest monsoon. High content of phytoplankton in the stomach was followed with high percentage of omega-3 of Bali Sardines. It showed that omega-3 content was highly related with the feeding pattern of Bali Sardines. This information is important for future food security, particularly for economy, diet, livelihoods of communities in the developing country.

S3-P12

Predator-prey synergism – A novel perspective in ecology

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“From an antagonistic to a synergistic predator prey perspective: Bifurcations in marine ecosystems” is the tile of a book that was published by Elsevier in 2014. The book presents predator-prey synergism as a novel perspective in ecology, defined as predator-prey relationships enhancing abundances of both predator and prey. The idea emerged during analyses of near-century long time series of observations of marine coastal ecosystems, but it is suggested that synergism may be important in some terrestrial systems too. Predator-prey synergism has wide-ranging implications for management of marine ecosystems and for theories in ecology and evolution. Resilience in marine ecosystems may be explained mechanistically by synergism, as may repeated incidents of bifurcations observed in the long time series. Bifurcations are sudden and persistent regime shifts as a result of gradually changing environmental conditions. Evidence suggests that the observed shifts originate in the plankton community, and are propagated to higher trophic levels by causing recruitment failure in fish. It is proposed that global warming may induce bifurcations, recruitment failure and substantially reduced fish abundances.

S3-P13 CANCELLED

Are northern anchovy caught in a "predator pit"?

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We constructed a Model of Intermediate Complexity (MICE) to determine whether top-down pressure is impacting the recovery of the central subpopulation of northern anchovy (*Engraulis mordax*) in the California Current. Recent biomass estimates indicate a collapse in the population which started after a major recruitment event in 2005, and has continued to the present. High concentrations of anchovy, however, have been observed nearshore during this time, for example in Monterey Bay and off San Diego, in central and southern California, respectively. The anchovy population tends to contract nearshore when abundances are low, creating a paradoxical impression of abundance. Major anchovy predators, such as California sea lions and humpback whales, have recovered from very low abundances during the 1950s, and may now be consuming a larger fraction of the anchovy population, especially under the presently low abundances and nearshore concentrations. Although current annual fishery catch levels of a few thousand tons are small by historical standards, current exploitation rates could be high given the low stock abundance. Both predation and fishing are modeled as top-down pressures on the central subpopulation of northern anchovy to test Bakun's "predator pit" theory (2006; Prog. Ocean 68:271).

S3-P14 ALSO TALK on MARCH 9, 16:40-17:00

Do jellyfish blooms affect small pelagic fishes in coastal marine environments?: A comparative analysis of three coastal ecosystems

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Scyphozoan jellyfish have several characteristics that place them in a potentially influential position for structuring energy flow through pelagic food webs, in that they have high rates of growth and reproduction, broad planktivorous diets, and few predators. Within eastern North Pacific ecosystems, abundances of the dominant scyphozoan (*Chrysaora* spp.) have fluctuated widely over recent decades, and we hypothesize that so too has their impact upon pelagic ecosystems. We examined the role of these large jellyfish as ecosystem structuring agents in three coastal ecosystems, the Eastern Bering Sea (EBS), the Northern California Current (NCC), and the mid-Coastal Gulf of Alaska region (CGoA). We are investigating the potential impact that jellyfish blooms have upon small planktivorous fish through analyses of the relationships between jellyfish and forage fish spatial overlap, abundance timeseries, and through ecosystem model simulations. Jellyfish can place a large demand upon ecosystem production. In the EBS ecosystem, 4% of total ecosystem production is required to support the *Chrysaora* population -- roughly 20-fold more energy than is used by forage fish. In the NCC, *Chrysaora* are similarly supported by 3% of the total ecosystem production; but in the CGoA, where jellyfish are less abundant, only 0.1% of the total ecosystem production is used. In ecosystems where jellyfish are abundant, model simulations show the consequences of interannual variability in *Chrysaora* abundance. In the EBS for example, models representing high (2009-2014) and low (2004-2008) jellyfish regimes show that productivity among small planktivorous fish is inversely related to jellyfish abundance.

S3-P15

The role of prey selectivity in shaping Arctic Cod distribution in the Chukchi Sea

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Arctic Cod (*Boragadus saida*) represent an important prey item in the Arctic food web including marine mammals and seabirds. Many factors influence Arctic Cod distribution such as life history, water temperature and prey availability. This study investigates the dynamics of Arctic Cod pelagic distribution in relation to prey abundance and biomass, and water masses in the vicinity of Barrow Canyon. We hypothesize that Arctic Cod abundance is highest where zooplankton abundance and biomass are high, independent of zooplankton size. Results show that high abundances of Arctic Cod occurred along the southern edge of Barrow Canyon where large and small zooplankton were aggregated. However, there were a few areas with increased Arctic Cod abundance in the northern edge of Barrow Canyon where zooplankton abundance was relatively low but aggregations of the lipid rich large copepod, *Calanus hyperboreous*, were found. Arctic Cod diet data indicate that Arctic Cod selected for the large lipid rich *Calanus glacialis* even in areas where small copepod biomass was five times higher (30 vs 150 mg/m^3). Non-metric multidimensional scaling indicates that *C. glacialis* copepods are the dominant prey item in Arctic Cod diet followed by larvaceans. In Addition, Arctic Cod abundance was highest where cold Bering Chukchi Winter Water flowed onto the shelf, and was lowest where temperatures were > 4 degrees Celsius. Our findings indicate that prey selectivity play a fundamental role in Arctic Cod distribution and that an increase in water temperature may prevent Arctic Cod from feeding in areas of high prey abundance.

Session 4
Poster Presentations

Comparison of methods for assessment of small pelagic fish populations

S4-P1

Estimation of total egg production from CUFES data and comparison with acoustics: An example with anchovy and sardine in the Bay of Biscay

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The CUFES (Continuous Underway Fish Egg Sampler) is used during the PELGAS small pelagic spring survey in the Bay of Biscay by Ifremer, onboard the R/V Thalassa. This sampler provides a continuous estimation of surface egg abundance over the spawning habitat of anchovy and sardine close or at peak spawning. Our procedure for deriving the total daily egg production (Ptot) is made of three components : (i) a one-dimension vertical dynamic distribution model, (ii) an egg mortality estimation, and (iii) a spatial interpolation procedure to integrate over the whole spawning area. The vertical model is used to derive the vertically integrated egg abundance from the surface abundance for each CUFES sample. It uses the water density profile from the closest CTD cast performed during the survey, together with the estimation of the egg specific gravity, and is forced by the wind and tide for vertical mixing. The local egg production (P0) is then estimated from the abundance at three stages averaged over a sufficient number of CUFES, from which a mortality curve is derived. The comparison of Ptot with simultaneous acoustic assessment of the SSB allows the estimation of daily specific fecundity. The analysis of the 2000-2016 time-series reveals an average fecundity in agreement with the traditional biological observations of fecundity parameters, for both anchovy and sardine. However, strong deviation occur for some years, providing a warning either for the quality of the acoustic estimation, or the daily fecundity to be applied in the traditional Daily Egg Production Method.

S4-P2

Morphology, meristic, and genetic approach for *Sardinella lemuru* migration in Bali Strait and South Java

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Sardinella lemuru is important pelagic species in Indonesia, mainly Bali Strait, because nearly 80% of *S. lemuru* caught in Bali Strait. Early 1990s known that *S. lemuru* in East Java migrated from Bali Strait to Madura Strait and Sendang Biru Water (South Java Sea). However, last 10-years, it was only caught in Bali Strait and South Java Sea. Therefore, the aim of this study was to ascertain *S. lemuru* resources by analyzed the characteristics of morphology, meristic, and genetic of *S. lemuru* catched in Bali Strait and Sendang Biru Water. The results showed that there was almost no difference in morphology between Bali Strait and Sendang Biru *S. lemuru*, except for their weight. Samples M26 and M29 had a very close relationship, with an index of similarity of 96%. In meristic, all parameter were the same except for the number of hard dorsal and pectoral fins. Samples M1, M2, S4, S5, M13, M18, S20 and S21 had a similarity index between 98-99%. Analysis of genetic variation using RAPD with OPA 1, 4, 7, 8 and 11, showed total 87 DNA fragments amplified. The genetic variation that had the closest relationship found in samples M6 and M7, M15 and S26, S8 and S3, S13 and S24, and S20 and S22, with distance 100, 98, 97, 94 and 94%, respectively. Morphology, meristic, and genetic variation, as well as oceanographic parameters analysis in the area of fishing ground have informed us the *S. lemuru* migration track for better management.

S4-P3 CANCELLED

Reproductive biology, population dynamics and fishing of the Broadband anchovy *Anchoviella lepidentostole* in Southeast Brazil

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The Broadband anchovy, *Anchoviella lepidentostole*, is a traditional fishery resource with relevant economic and social importance in the southern coast of the State of São Paulo. This anadromous species is caught with gillnets and beach seines, in the rainy and warm season from September to March (spring/summer), when dense shoals migrate upstream for spawning in the Ribeira-de-Iguape River. About 4000 t was the highest record in landings in the 1970s, when about 500 fishermen were in activity. At present, 1,800 artisanal fishermen catch about 800 t per year. Given its importance, some studies were carried out in 1980s, but the absence of recent data prevents adjustments in legislation for a co-management. Thus, the aim of the present study was to provide data on the reproduction growth, and mortality. Data of 4,484 specimens (50.9% females) were obtained in five localities along the river, from the mouth up to about 100 km, during three commercial fishing periods (2013-2015). FISAT II was used for growth and mortality estimates. CPUE estimates were estimated from the official fishing statistics. Size structure, length-weight relationship by sex, sexual ratio by locality, and other basic characteristics of the reproductive biology are described. Only adults of both sexes are present in catches making up at least three cohorts. Although huge difference in relation to baseline data, it is conclude that the stock is under a moderate exploitation rate, thus corroborating the relevance of the closure of the fishery for a month, during the peak of the reproductive period.

S4-P4

Technique for assessment of saury concentration in the lighted area

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An algorithm for calculating the distribution of surface and underwater light produced by the fish gathering lamps was developed. All the calculations may be easily implemented in the Microsoft © Office Excel program. As for the fishing vessel STR-420, surface fishing light distribution around the vessel exhibits an irregular pattern that depends on the lamps arrangement. Operating parameters for a new saury lift net were defined. The effective volume of the net cage is estimated at more than 7000 m3. As illustrated by a conventional example, the density of saury distribution in the natural environment could be estimated based on a catch value by the lift net.

The developed algorithm allows achieving an optimal gathering lamp arrangement that provides more even lighting and, therefore, larger illuminated area for attraction of fish with positive phototaxis, like Pacific saury.

Session 5
Poster Presentations

Future challenges for ecosystem-based management of highly variable fish populations

S5-P1

Who did it?: Assessing potential pressures on small pelagic fish populations of the NW Mediterranean Sea using a qualitative modelling approach

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Small pelagic fishes (SPF) in the NW Mediterranean Sea are key elements of the marine food web and are dominant in terms of biomass and catches. However, important changes have been observed in recent decades: for example, declines in biomass and landings of European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*), and an expansion of Round sardinella (*Sardinella aurita*). Fluctuations in populations of SPF have been linked to environmental changes that directly influence annual recruitment and growth. The role of climate change in affecting the composition of plankton has also been suggested to explain the recent declines, while other causes could be the recovery of predators, competition with other pelagic organisms that feed on zooplankton and can also prey on early life phases of SPF (e.g., jellyfish), interspecific competition for food, or impacts from over exploitation and fisheries mismanagement. To test the role of these potential pressures, we developed qualitative models of the NW Mediterranean pelagic food web. We used the methodology of sign directed graphs in combination with an analysis of Bayesian belief networks to compare alternative model structures and explore how SPF species, preys and predators abundance and life expectancy may have responded to different disturbances. Observations from the literature and available data were used to validate predicted directions of change. A combination of factors, including an increase of fishing impact, an increase of sea surface temperature and food-web interactions provide the most plausible insights into potential pressures on SPF in the study area.

S5-P2

Atlantic small pelagic resources in Morocco: Which place in the north-west African sub-region?

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Small pelagic resources off the North West African sub-region (NOA) are of incontestable economic importance for the countries of the sub region. Most of these resources have a cross-border distribution and are the subject of national as well as regional exploitation. Their cross-border nature aroused a large-scale monitoring introduced in the countries of the sub region within the framework of CECAF. The importance of each small pelagic species varies from country to country, according to its abundance, distribution and its local fishing specifications. However, these resources are especially predominant at the Moroccan side, namely its Atlantic coast that contains more than 50% of biomass and more than 40% of production of small pelagic fish in the sub-region. This work attempts to locate the exploitation of small pelagic in Morocco in the context of its large sub-regional level, by analyzing different fisheries indicators (catch, effort... etc.) and stocks indicators (biomass, distributions, biological reference points... etc.). Furthermore, this contribution try to highlight the importance of monitoring these resources across the entire sub-region in the CECAF framework, that helps to assess different shared stocks and provide necessary indicators to set appropriate sustainable management policies. An overview of the management measures applied in the Moroccan case is also presented as a typical example of small pelagic management in the NOA region.

Session 6
Poster Presentations

Small pelagic fish and humans – Social, economic and institutional dimensions

S6-P1

Stocks, harvest and potential use of Black and Caspian Sea sprat *Clupeonella cultriventris* in the Dnieper River Basin, Ukraine

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The Black and Caspian Sea sprat, *Clupeonella cultriventris*, is the most numerous small pelagic marine fish that occupied free niche of zooplanctivores in littoral zone of the Dnieper Reservoirs. In autumn 2015, like in previous years, trawl catches consisted of 0+ – 3+ aged fish. About 55 % were underyearlings 45 – 48 mm length and 0,7 – 1,2 g weight. Within 1960th –1980th fish harvest of this species was about 5000 – 8000 tonnes per year or 30 % of total catch. Such activity effectively controlled stocks and spreading of this nonindigenous species. However, since 1990th to present high prices for fuels and lubricants and low prices for *C. cultriventris* made its commercial trawling non-value-added. Therefore, its annual real commercial harvest in 2010 – 2015 steeply decreased to about 500 tonnes. After that stocks were underfished and these quantities of *C. cultriventris* directly disrupted food webs by competing with native planktivores and had huge negative environmental effect on fish recruitment by reducing prey for fish larvae. From other hand, *C. cultriventris* was an alternative prey for native predators such as Pikeperch *Sander lucioperca*, Nothern pike *Esox lucius* and European perch *Perca fluviatilis*. Calculation showed that stocking of about 4 million pikeperch underyearlings could effectively reduce number of Black and Caspian Sea sprat and allow getting additionally more than 1000 tonnes of pikeperch harvest each year in four years term. However, this stocking should be annual and depend on *C. cultriventris* limits.

S6-P2

Small vs Big: Lessons from small-scale small pelagic fisheries facing global changes

Manuel **Muntoni** and Ratana Chuenpagdee

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Small-scale small pelagic fisheries are recognized as a major provider for food security, employment and income. They play an important economical and social role, particularly for developing coastal communities, where small pelagic represent an important source of subsistence. However, these fisheries are dealing with several challenges brought about by global changes (environmental, climate, market and governance), which may directly affect their viability. Environmental changes have an effect on fisheries system and, as a consequence, the human system changes its behaviour altering, in turn, the environmental system. These reciprocal interactions between the human and ecosystem compartments, directly affect the small-scale fisheries, ultimately affecting their profitability and sustainability. The responses given by the small-scale small pelagic fisheries can be different, in respect of their vulnerability, their governability and their capability to cope with the change. In order to increase the knowledge about these interactions and how small-scale fishing communities react and adapt to global changes, we collect case-studies from all over the world and, following the I-ADApT framework, we developed a typology, identifying common issues and successful strategies for coping with the changes. Learning from similar cases can help in preventing and identifying potential crises, thus representing a crucial step to improve governability, minimizing the vulnerability, and promoting sustainability of small pelagic fisheries.

Keywords: Small-scale fisheries, small pelagic, global change, climate, market, environment, governance, social, vulnerability

S6-P3

Growth opportunities for artisanal fisheries in México

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Currently the fishing cooperatives in Mexico are of great importance for the integration of economic, social and environmental objectives that are part of their daily work. Collective action to build and strengthen fishing communities have had an impact on the quality of life of its inhabitants becoming the cooperative in a social and economic institution of deep cultural roots in coastal areas. Sinaloa is one of the states of northwestern Mexico that contributes most to the economy of the region for its concentration of biggest fleet, fishery processing, producing shrimp farms, coastal fishing cooperatives and just over 15% of the population national fisheries; this is more than 45 thousand direct jobs and a considerable number of indirect jobs. Public policy for the cooperative greatest impact has been the opening of shrimping private investment, creating strong competition between private investors and fishing cooperatives; and other factors such as deterioration of coastal ecosystems, the management capacity of government support and economic management mechanisms of cooperatives under the scheme of family organization. In this context coastal fishing cooperatives are challenged to manage their investment projects with strategic advantages in exploiting growth opportunities to compete in the global marketplace by optimizing the value of their products; supported risk relationships, organization, and entrepreneurship as a research.

S6-P4

How well does Canada manage forage fish fisheries?

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In Canada, several forage fish species are commercially harvested, the most important being Atlantic and Pacific herring, capelin, and Atlantic mackerel. WWF evaluated 27 stocks across Canada based on 9 criteria evaluating the stock dynamics – population abundance, status, trends, environmental drivers and monitoring as well as information about dependent predators population abundance, trends and foraging grounds. The overall management strategy goal was to regulate fishing intensity so that there was a low risk of significantly affecting dependent predators. Next, to gather feedbacks and identify key areas of focus for immediate next steps, two focus groups were held at the 4th International Marine of Conservation Congress. The analysis revealed that, based on the Canadian precautionary approach framework, 75% of the fisheries assessed, the stock status was unknown, three were in the critical zone, including two Atlantic herring stocks in the Gulf St. Lawrence and Atlantic mackerel in the Maritimes region. In all cases, fisheries management did not sufficiently account for predator needs and the environmental drivers on population dynamics were largely unknown. Over 40 representatives from Canadian governments and academia from around the world identified the following top priorities for Canada: Implement Ecosystem Based Fisheries Management, support science for all forage fish, particularly capelin in Atlantic Canada, work collaboratively with stakeholders, including Fisheries and Oceans Canada and support existing efforts, prioritize traditional and territorial rights and stewardship from fish harvesters, and develop a communication campaign to gain political capital in support of the conservation of these species.

S6-P5

Interannual variability in sardine fisheries in the northern Zamboanga Peninsula, Philippines: Understanding human-environment synergy in sustainable fisheries management

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Sardine (Clupeiformes: Clupeidae) fisheries in the Zamboanga peninsula, southern Philippines contribute a significant portion to the country's export market. Concerns on dwindling stocks motivated the Philippine government to implement an annual fishing closure for a period of three months (December to February) to protect spawning. Monitoring of sardine fisheries carried out under two government-funded research projects looked into the spatio-temporal dynamics of sardine fisheries in the northern Zamboanga peninsula (NZP). Conventional dockside and biological surveys were supplemented by a satellite-based, participatory research approach called Research in Sardine Volunteer Program (RSVP) to produce time-series maps of fishing effort, catch data, and potential spawning grounds. Landed catch data covering the period 2009-2014 show interannual variability in sardine production possibly influenced by seasonal or climatic events, food availability, and changes in fishing effort. Annual variations in recruitment of the dominant Bali sardine *Sardinella lemuru* are driven by monsoonal upwelling and its vulnerability to climate-associated factors such as ENSO-induced collapse in chlorophyll levels in 2008. Overfishing on sardine stocks of NZP is evident from highly intensive fishing effort, incidences of fishing violations, continuous fishing on juveniles and decreasing size at sexual maturity. Geo-referenced effort maps show that both industrial and artisanal fishing on sardine generally occurs within municipal (nearshore) waters – a constant source of conflict in resource use in the region. A brief analysis of impacts of the sardine fishing closure, synergy of human and environmental factors, and recommendations to improve management policy toward sustaining the country's sardine stocks are discussed.

Workshop 5
Poster Presentation

Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies

W5-P1

Biological parameter estimation for a bioenergetics model of chub mackerel (*Scomber japonicus*)

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The chub mackerel (*Scomber japonicus*) is one an important exploited species in the western North Pacific. Catch and stock data for this species have shown large fluctuations. In recent years, the total biomass has tended to increase due to strong recruitment year-classes and effective fishery management. However, little is known about the causes of strong recruitment, which makes it difficult to predict recruitment and total biomass over time. Previous studies showed that sea surface temperature, sea surface current, and prey environment play important roles in growth and recruitment of chub mackerel. However, it is difficult to observe the environments that individual fish experience and thus understand the growth response of the fish. To quantify the importance of various environmental factors on growth and hence on recruitment, we are developing an individual based model (IBM) which simulates the full life cycle of chub mackerel. In this study, we estimated the biological parameters on consumption and metabolism for the IBM by reviewing observations and modeling results of previous laboratory studies. The metabolism parameters (dependency for temperature, activity, and fish wet weight) were reasonably estimated. However, the temperature dependency on consumption differed greatly depending on prey items. Further laboratory experiments seemed to be essential to establish a predictive bioenergetics model for chub mackerel.

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