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Report of PICES/ISC Working Group 34 on Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish

NORTH PACIFIC MARINE SCIENCE ORGANIZATION

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Report of PICES/ISCWorking Group 34 on Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish

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Front cover:
Pacific bluefin tuna (*Thunnus orientalis*) is one of the key highly migratory species studied by Working Group 34. A photo of this species was taken at the Osaka Kaiyukan Aquarium, Japan. (Photo credit: Daiju Azuma)

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Executive Summary

Working Group 34 on *Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish* was proposed as a joint working group between PICES and the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). The main purpose of the group was to collaborate on deriving habitat models for albacore tuna and other Highly Migratory Species (HMS) in the North Pacific. Seven Terms of Reference for the Working Group emphasized collaborative activities across the scientific and management communities to identify datasets, build models, and communicate results. In the four years since Working Group 34 was formed, research by group members has advanced understanding of the drivers of distribution and productivity for some commercially important HMS in the North Pacific. However, this research has largely proceeded within member countries using fishery-dependent data available from their national fishing fleets. This is partially due to the difficulties associated with sharing confidential fishery-dependent data among countries, at the spatial and temporal resolutions most useful for building distribution models. A lack of inter-sessional meetings also limited cross-institution collaborations. Despite these challenges, Working Group 34 produced several publications, and multiple presentations at PICES Annual Meetings and other major international conferences. The group also hosted or co-hosted two workshops and two topic sessions at PICES Annual Meetings between 2016 and 2019. Research by Working Group members in particular improved our knowledge of distribution drivers for albacore and Pacific bluefin tuna, and recruitment predictors for Pacific bluefin tuna. However, many questions remain. To highlight these knowledge gaps, research recommendations have been included under the achievements summary of each Term of Reference.

Introduction

Working Group 34 on *Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish* was formed with the aim of leveraging international collaborative relationships to improve understanding of factors driving the distribution and productivity of highly migratory fishes in the North Pacific. The Working Group was chaired by scientists from both PICES (Appendix 2) and the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). The ISC is an intergovernmental body dedicated to advancing fishery science of the North Pacific tuna and tuna-like fishes through cooperation and collaboration. PICES has similar goals (*i.e.*, to promote and coordinate marine research in the northern North Pacific, and to advance scientific knowledge about the ocean environment, global weather and climate change, living resources and their ecosystems), but focuses much less on stock assessment and management activities. The joint Working Group was therefore proposed as a mechanism to link the science, assessment, and management communities, and thus to enhance understanding of the drivers of Highly Migratory Species (HMS) distributions in the PICES domain.

The Terms of Reference and work plan initially focused on albacore tuna (*Thunnus alalunga*) as a case study, due to its distribution covering much of the PICES domain. This species is also not currently considered to be overfished, or undergoing overfishing, and so it was hypothesized that environmental influences on its distribution and recruitment may be more easily discernable than for more heavily exploited species such as Pacific bluefin tuna (*Thunnus orientalis*). However, research by Working Group members focused on both species, as well as some other pelagic fishes, during the term of the group.

The Terms of Reference (Appendix 1) for the Working Group highlighted the need to understand how oceanographic conditions influence the distribution, movement, and recruitment of highly migratory fishes. Many of these species are important top predators in North Pacific ecosystems, and some support economically important fisheries. However, their extensive migratory movements across broad geographic ranges can complicate understanding of their ecology and population structure, as well as presenting difficulties for effective stock assessment. In addition, recruitment to highly migratory fish populations is often extremely variable, and only weakly correlated with spawning stock biomass. The formation of Working Group 34 was designed to address some of these issues through targeted fisheries oceanography studies of key species.

WG 34 Achievements with Respect to Terms of Reference

1. *Promote research between PICES and ISC communities directed at understanding oceanographic conditions that provide suitable habitat for large, highly migratory pelagic fishes (specifically albacore tuna) in the North Pacific Ocean.*

Highly migratory fish species such as tunas and billfishes are ecologically important top predators in the North Pacific Ocean, as well as in other oceans around the world. They are fished by multiple fishing fleets using a wide variety of gears, with various national and international fisheries targeting newly recruited individuals (Yamada *et al*., 2006), juvenile animals (Childers *et al*., 2011), and mature adults (Itoh, 2006). The migratory paths of HMS can cover entire ocean basins (Fujioka *et al*., 2018), and can allow fish to move between spawning and foraging grounds. The more endothermic tuna species, such as albacore and Pacific bluefin tuna, can maintain their internal body temperatures above ambient water temperatures, which has allowed them to exploit productive temperate foraging grounds in the North Pacific and in Eastern Boundary Upwelling Systems, such as the California Current. However, like most other tuna species, their spawning activity is limited to more oligotrophic regions with warmer waters (greater than approximately 20°C), conditions which are presumed to enhance the survival of larvae (Muhling *et al*., 2017). Albacore and Pacific bluefin tuna must therefore travel long distances between foraging and spawning areas, and the timing and extent of these movements can be sensitive to environmental conditions. As a result, fisheries targeting these species may have to adapt to shifting phenology, distributions, and abundance of HMS as environmental variability and climate change impact their productivity and movements.

In addition to challenging fishing fleets and fishing communities, environmentally driven shifts in the distributions of managed species can cause problems if stock assessment and management frameworks are not robust to changes in availability among different fleets. Unlike many coastal or benthic fish species, which are the focus of other PICES working groups, HMS are not bound to particular benthic habitats or bottom types. They often move through the Exclusive Economic Zones of multiple countries, as well as the high seas, throughout their life cycles. Shifts in species distributions therefore have implications for transboundary management and exploitation of shared resources among nations, as well as the future effectiveness of current arrangements between states and countries. These management measures may be increasingly challenged as climate change will continue to result in novel environmental conditions across the North Pacific.

Significant progress has been made in the four years since the Working Group was initiated on understanding habitat use of highly migratory species in the North Pacific, particularly with respect to albacore and Pacific bluefin tuna. Research results have highlighted the important roles of species-specific thermal limits in determining foraging areas and migratory corridors. There is also some evidence that changes in the distributions of prey fields can have substantial impacts on the distribution of HMS, both at seasonal and interannual scales. Decadal-scale oceanographic variability in the North Pacific Transition Zone also appears important for migratory paths in juvenile albacore, potentially due

to impacts on foraging conditions. Strong fluctuations in the availability of prey, such as Japanese sardine in the western Pacific, and northern anchovy in the eastern Pacific, may also drive large-scale movements of juvenile albacore, impacting their availability to fishing fleets. As well as being important for broad-scale movements of albacore across the North Pacific, prey fields may also drive interannual variability in abundances of Pacific bluefin tuna in the Southern California Bight. Although both of these species are considered to be temperate tunas, albacore fisheries in the eastern North Pacific appear to be adversely impacted by anomalously warm conditions, whereas catches of Pacific bluefin tuna in the California Current region were at record levels during the recent (2015–2016) marine heatwave.

However, this research has proceeded largely within PICES member countries, with some limited collaboration between scientists from different institutions. For example, some spatially aggregated data were shared between Working Group members from the USA and Canada, and some discussions were initiated between the USA and Japan regarding sharing tracks of archivally tagged fish. This lack of coordinated collaboration was partially due to the difficulties associated with sharing confidential fishery-dependent data among countries. This is a long-standing barrier to international collaborations among countries when analyses require set-by-set or un-aggregated fishery-dependent data. The lack of regular meetings among Working Group members outside of PICES Annual Meetings also limited collaborations, as did the lack of coordination between PICES scientists and the ISC. Nevertheless, two publications addressing Term of Reference #1 have been produced, and are listed in Appendix 3**,** with others in preparation. Relevant presentations at PICES and other international scientific meetings with Working Group members as co-authors are also shown in Appendix 4.

To best advance the research themes commenced under Term of Reference #1, more attention needs to be paid to the physiological mechanisms driving observed patterns of species distributions and movements. This is consistent with a general push by the climate change impacts community to make biological models more mechanistic, instead of relying solely on correlative relationships. In the future, we also consider that it would be beneficial to improve communication between the scientific community, including Working Group 34 members, and the population dynamics and stock assessment communities. The two groups should continue to explore potential collaborations, including through the ISC, to determine where distribution modeling results could be useful for assessment and management of HMS. This can be difficult with current restrictions on travel but could lead to more coordinated efforts, including scientists across countries, and improve the applicability of fisheries oceanography research to fisheries management.

2. *Facilitate communication, regular exchange of information and organization of meetings to discuss and publish data, methodologies and results of research outlined above.*

Discussions among Working Group members from different member countries were largely restricted to the workshops and topic sessions held at each PICES Annual Meeting from 2016 through 2019. In addition, the results of Working Group research and related publications were presented to the ISC in 2019, as part of the National Report of the USA, presented by the NOAA National Marine Fisheries Service. (Plenary 9, 19th Meeting of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean. Taiwan, Taiwan, July 11–15, 2019).

As highlighted above, sharing of fishery-dependent data among member countries is very difficult. However, analyses on aggregated data, or analyses of confidential data within countries but using

common methodologies, may be more achievable. This would require improved communication between the PICES and ISC/stock assessment communities. We note that several of the presentations given in the FIS/POC/BIO/HD Topic Session (S11): "*Incorporating ecosystem variability and climate change into fisheries management: Progress and challenges for EBFM in the 21st century*" at PICES-2019 highlighted that environmental information can be incorporated in the assessment and management framework at many stages in the process. These opportunities include at the hypothesis generation stage, as qualitative context, in the index standardization process or in the stock assessment model itself, or at the management advice stage. As the stock assessment models currently used for HMS often do not lend themselves to direct incorporation of environmental covariates, future work in these areas should consider where in the assessment and management procedures environmental considerations may be useful. This scoping could then identify target areas for continuing research.

3. *Identify relevant environmental and distribution data sets for derivation of habitat models for albacore tuna, and if available for other key large pelagic fish species. Use these data to develop habitat models (and quantify model uncertainty), that identify oceanographic conditions that drive distribution of albacore tuna and predict fishery CPUE 'hot spots'.*

A key requirement for building statistical species distribution models is the availability of both biological and environmental datasets. Biological data for commercially exploited species can be sourced from fishery-dependent observations, which can include self-reported industry logbooks, records from government-employed onboard observers, or electronic monitoring systems, such as vessel monitoring systems. In some cases, observations from fishery-independent surveys are available. Fishery-independent data have several advantages, including that they are often from statistically-designed survey grids, which cover times, areas, and species of particular interest. They may also include life stages not present in commercial or recreational fishing data, such as larvae or early juveniles (*e.g.*, Ohshimo *et al.*, 2017). However, at-sea surveys are expensive and time-consuming to run, particularly for species which are found across very large spatial areas. As result, the majority of data available for modeling HMS distributions comes from the fishing industry. In contrast, environmental predictors for use in species distribution models are mostly from remotely-sensed sources, or from ocean models, rather than at-sea observations. This is particularly true in recent decades, as these types of remote observations and ocean models have become more sophisticated and more widely available. However, *in situ* observations are still highly valuable for verification and ground-truthing, and for assimilation into ocean models.

For the species distribution models developed as part of Working Group 34, environmental data were obtained from satellite observations, global physical and biogeochemical models, and higher resolution regional models (*e.g.*, ROMS, Neveu *et al.*, 2016). These were usually freely available, or obtained through partnerships among academic and/or government institutions. Biological data from fishery-independent surveys were also available in some regions, and were used to build habitat models for some albacore prey species (*e.g.*, Muhling *et al.*, 2019, Appendix 3). However, distribution data for albacore and other highly migratory pelagic fishes were mostly available from commercial and recreational fisheries. These data are usually considered to be confidential when in raw, un-aggregated format, and are typically not able to be shared among scientists from different countries. As a result, habitat modeling activities relevant to Working Group 34 mostly focused on the geographic ranges covered by national fishing fleets, rather than attempting to combine data from different countries. Despite these limitations, research by Working Group members and their colleagues produced new

insights into drivers of distribution of juvenile albacore targeted by the U.S. fleet (Muhling *et al*. 2018–2019 presentations, Appendix 4), and adult albacore targeted by the Japanese longline fleet (Nakatsugawa *et al*. 2018 presentation, Appendix 4).

Future research recommendations relevant to Term of Reference #2 include the need to define habitat and movements of HMS throughout their geographic ranges, and across different life stages. This will be most effectively achieved if fishery-dependent and fishery-independent datasets from different member countries can be analyzed together, although this is generally difficult to do, as noted above. An improved understanding of the physiological drivers of migration and foraging behaviors from laboratory and/or modeling studies may also help to build more mechanistic distribution models for HMS. These will be particularly valuable as climate change continues to result in novel environmental conditions across the North Pacific.

4. *Identify relevant climate indices, demographic parameters and recruitment indices for investigation of climate driven variability in ocean state and productivity of albacore tuna, and if available for other key large pelagic fish species. Use these data to investigate linkages between large-scale climate indices and fish productivity.*

Many population dynamics and stock assessment models assume that recruitment to fish populations is largely dependent on adult spawning biomass (Hilborn and Walters, 1992). However, observed relationships between annual recruitment and spawning biomass are often extremely noisy, and in some species recruitment appears to vary almost independently (Lowerre-Barbieri *et al*., 2017). Some of this variability in recruitment can be attributed to environmental factors. There are multiple mechanisms by which environmental conditions can impact recruitment, including through larval growth and feeding, by varying oceanographic connections between spawning grounds and nursery areas, and through impacts on maternal condition. Although there is a long history of fisheries oceanography studies linking environmental conditions to recruitment in exploited fishes (*e.g*., Rothschild, 2000; Megrey *et al*., 2005), these relationships often fail when challenged with new data or different analysis techniques (Myers, 1998). As a result, environmentally-driven indices of recruitment are rarely included in assessment and management processes, or as part of ecosystem-based management frameworks. However, if robust relationships based on mechanistic understanding can be developed, there is potential for both short-term early warnings of falling stock productivity and enhanced understanding of how productivity may change in the longer term (*e.g*., Tommasi *et al*., 2017).

Much of the work on variable recruitment in North Pacific albacore was conducted by Dr. Desiree Tommasi (University of California – Santa Cruz and NOAA), who is leading the current Management Strategy Evaluation (MSE) of this stock. Initial work (Muhling *et al*. presentation, 2018 Ocean Sciences meeting, Appendix 4) showed that albacore recruitment was not strongly predictable by environmental or climate variables. This finding was likely due to both the broad geographic area over which albacore spawn and our relatively limited understanding of interannual variability in larval distribution and survival. As a result, the work relevant to the MSE (Tommasi 2018–2019 presentations, Appendix 4) has focused on the effects of different recruitment scenarios, rather than modeling environmental influences on recruitment explicitly. In contrast, recruitment to the Pacific bluefin tuna stock was found to be strongly predictable based on environmental conditions near spawning grounds (Muhling *et al*., 2018, Appendix 3). In particular, warmer temperatures in juvenile nursery grounds in the late summer and autumn were associated with higher levels of recruitment in this species. Unlike albacore, Pacific bluefin tuna spawn in well-defined, spatially restricted areas within a short spawning season, their early

life history is relatively well understood, and catches of age-0 fish around coastal Japan provide a very reliable index of recruitment. These results may allow the advance prediction of recruitment for this species if skillful multiannual temperature forecasts are available (Tommasi and Muhling 2019 presentation, Appendix 4). The sensitivity of Pacific bluefin tuna early life stages to temperature may also have implications for their phenology as ocean temperatures continue to warm (Kimura *et al*. 2017–2018 presentations, Appendix 4).

In order to predict near-term and long-term future changes in recruitment of North Pacific HMS, improved mechanistic understanding of spawning and larval ecology will likely be required. While statistical correlations between environmental time series and annual recruitment can be helpful, without knowledge of the physiological processes underpinning these correlations, confidence in the stationarity of the relationships going into the future can be limited. In addition, outstanding questions regarding spatial stock structure in species such as albacore will need to be resolved. This species is currently managed and assessed as one stock across the North Pacific. If future research suggests that there is spatial structure in spawning, genetic types, or movement of young juveniles onto nursery grounds, then current hypotheses regarding drivers of recruitment in the species will need to be re-assessed.

5. *Hold three workshops, one each year of the duration of the Working Group: with the first and third workshops held in conjunction with the PICES Annual Meeting (PICES-2016, USA and PICES-2018, Japan), and the second workshop held in conjunction with the ISC Plenary Meeting (July 2017, location TBD). Reports of these workshops will be jointly published by PICES and the ISC.*

Workshops were held as planned at the 2016 and 2017 PICES Annual Meetings. In addition, a topic session on "*Applying ecosystem considerations in science advice for managing highly migratory species*" was held at PICES-2018 (session summary, Appendix 5), and a broader topic session on "*Incorporating ecosystem variability and climate change into fisheries management"* was co-hosted at PICES-2019 (session summary, Appendix 5). The 2019 topic session was particularly well-attended, including by NOAA laboratory directors and ISC representatives, and presentations given in this session highlighted that North Pacific Ecosystem Based Fishery Management frameworks have advanced substantially in the past several years. Workshops were not held at ISC plenary sessions, but results of the Working Group were reported to the ISC at the 2019 Plenary, as part of the National Report of the USA, presented by the NOAA National Marine Fisheries Service. The topic session at PICES-2018 was also co-sponsored by the ISC, and Dr. Steve Teo co-chaired the session on their behalf.

6. *Produce peer-reviewed publications of scientific results.*

Publications resulting from Working Group activities are presented in Appendix 3. Additional publications are being prepared, with some preliminary results of these were presented at PICES-2018 and PICES-2019. These publications address many of the research questions outlined under the original Terms of Reference, particularly with respect to determining the drivers of distribution shifts and recruitment variability in albacore and Pacific bluefin tuna.

7. *Publish a final report summarizing the results of the WG as a PICES Scientific Report.*

Conclusions and Future Plans

Working Group 34 was established to advance understanding of how distribution and productivity of highly migratory pelagic fishes respond to their oceanographic environment. Research by multiple Working Group members has addressed the aims set out under the initial Terms of Reference. However work has proceeded largely within member countries, with limited collaboration among institutions. This was partly due to the difficulties associated with sharing confidential fishery-dependent data, but also potentially due to a lack of inter-sessional meetings of the group. Despite these limitations, the Working Group hosted or co-hosted two workshops and two topic sessions at PICES Annual Meetings between 2016 and 2019. Research from Working Group members addressing the objectives of the group has been published in peer-reviewed journals, with more manuscripts in the preparatory stages. In addition, a large number of presentations have been given on research relevant to the Terms of Reference, both at PICES Annual Meetings and other major international conferences.

We recommend that future work include studies focused on determining the biological mechanisms underlying observed shifts in distribution and productivity of HMS in the North Pacific to enhance our ability to predict future changes. We also recommend that communication be improved between scientists from PICES and the ISC, to explore ways in which PICES research could be applicable to existing management frameworks. Although no follow-up working group has been proposed, research relevant to Working Group 34 is continuing under some external grants, such as the Future Seas project in the United States (www.future-seas.com), and within the home scientific institutions of Working Group members.

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Appendix 1

WG 34 Terms of Reference

WG 34 term: 2015–2018
Extended 1 year to 2019
Parent Committee: FIS

1. Promote research between PICES and ISC communities directed at understanding oceanographic conditions that provide suitable habitat for large, highly migratory pelagic fishes (specifically albacore tuna) in the North Pacific Ocean;
2. Facilitate communication, regular exchange of information and organization of meetings to discuss and publish data, methodologies and results of research outlined above;
3. Identify relevant environmental and distribution data sets for derivation of habitat models for albacore tuna, and if available for other key large pelagic fish species. Use these data to develop habitat models (and quantify model uncertainty), that identify oceanographic conditions that drive distribution of albacore tuna and predict fishery CPUE 'hot spots';
4. Identify relevant climate indices, demographic parameters and recruitment indices for investigation of climate driven variability in ocean state and productivity of albacore tuna, and if available for other key large pelagic fish species. Use these data to investigate linkages between large-scale climate indices and fish productivity;
5. Hold three workshops, one each year of the duration of the Working Group: with the first and third workshops held in conjunction with the PICES Annual Meeting (PICES-2016, USA and PICES-2018, Japan), and the second workshop held in conjunction with the ISC Plenary Meeting (July 2017, location TBD). Reports of these workshops will be jointly published by PICES and the ISC;
6. Produce peer-reviewed publications of scientific results;
7. Publish a final report summarizing the results of the WG as a PICES Scientific Report.

Appendix 2

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Appendix 3

Publications Related to WG 34 Research

Term of Reference #1

Muhling B.A., Brodie, S., Jacox, M., Snodgrass, O., Dewar, H., Tommasi, D., Edwards, C.A., Xu, Y., Snyder, S. and Childers, J. 2019. Dynamic habitat use of albacore and their primary prey species in the California Current System. Calcofi Reports 60.

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Term of Reference #4

Muhling, B.A., Tommasi, D., Ohshimo, S., Alexander, M.A. and **DiNardo, G.** 2018. Regional-scale surface temperature variability allows prediction of Pacific bluefin tuna recruitment. *ICES Journal of Marine Science* **75**: 1341–1352, https://doi.org/10.1093/icesjms/fsy017.

Appendix 4

Relevant Presentations by WG 34 Members

Term of Reference #1

PICES-2019, Victoria, BC, Canada

- Shifting distributions of fisheries for juvenile albacore in the eastern North Pacific
  Barbara Muhling, Desiree Tommasi
- Recent changes to the structure and function of the North Pacific albacore fishery
  Timothy Frawley, **Barbara Muhling**, Gwendal Le Fol, Megan Cimino, Steven Bograd, Elliott Hazen and Michael Jacox
- Using machine learning techniques to estimate pelagic species distributions under novel environmental conditions in the California Current system
  Barbara Muhling, Elliott Hazen, Stephanie Brodie and Michael Jacox

PICES-2018, Yokohama, Japan

- Spatio-temporal distribution of albacore *Thunnus alalunga* and its relationship with environmental changes in the Pacific Ocean
  Kento Nakatsugawa, Hidetada Kiyofuji and **Shingo Kimura**
- Migration paths and habitat use of albacore in the eastern North Pacific, with implications for surface fisheries
  Barbara Muhling, Desiree Tommasi, Owyn Snodgrass and Heidi Dewar

2018 Ocean Sciences Meeting, Portland, OR, USA

- Using habitat models to incorporate climate variability and assess the impact on Pacific Bluefin (*Thunnus orientalis*) tuna distributions and availability to commercial and recreational fishing fleets in the Eastern Pacific Ocean
  Rosa Runcie, **Barbara Muhling**, Elliott Hazen, Steven Bograd, Toby Garfield and **Gerard DiNardo**

2018 PICES Transition Zones Symposium, La Paz, Mexico

- North Pacific albacore distribution and migrations along transition zones
  Barbara Muhling, Desiree Tommasi and John Childers

PICES-2016, San Diego, CA, USA

- The impact of climate change on Pacific Bluefin (*Thunnus orientalis*) tuna distribution in the Eastern Pacific Ocean
  Rosa Runcie, **Gerard DiNardo**, Toby Garfield, Elliott Hazen, Steven Bograd, Kylie Scales and Jordan DiNardo

Term of Reference #4

PICES-2019, Victoria, BC, Canada

- Integration of multiannual climate predictions in the estimation of stock status and rebuilding time frames for highly migratory species
  Desiree Tommasi and **Barbara Muhling**

PICES-2018, Yokohama, Japan

- A management strategy evaluation framework to assess robustness of harvest guidelines for North Pacific Albacore tuna to variable productivity and distribution
  Desiree Tommasi, **Barbara Muhling**, Steve Teo and **Gerard DiNardo**
- Effects of global warming on spawning behavior of the Pacific bluefin tuna based on otolith oxygen stable isotope analysis
  Shingo Kimura, Yulina Hane, Yusuke Yokoyama, Yosuke Miyairi, Takayuki Ushikubo and Nobuhiro Ogawa

2018 Ocean Sciences Meeting, Portland, OR, USA

- Environmentally-informed recruitment indices for North Pacific albacore: Assessing management performance in a changing ocean
  Barbara Muhling and Desiree Tommasi

PICES-2017, Vladivostok, Russia

- Consequences of environmentally driven uncertainty in productivity for management of North Pacific Albacore tuna
  Desiree Tommasi, **Barbara Muhling**, Steven Teo and **Gerard Di Nardo**
- Oceanographic influences on the spawning and recruitment of Pacific bluefin tuna
  Barbara Muhling, Desiree Tommasi and **Gerard DiNardo**
- Development of methodology for analyses of larval ambient water temperature of Pacific bluefin tuna using SIMS
  Yulina V. Hane, **Shingo Kimura**, Yusuke Yokoyama, Yosuke Miyairi and Takayuki Ushikubo

Appendix 5

Meeting Report and Topic Session/Workshop Summaries from Past Annual Meetings

PICES-2016
November 2–13, 2016, San Diego, USA

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2016

FIS Workshop (W4)
Methods relating oceanographic conditions to the distribution of highly migratory species

Cosponsoring Organization: International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC)

Co-convenors: *Gerard DiNardo (USA), Chi-lu Sun (Chinese Taipei)*

Invited Speaker:
Barbara Muhling (NOAA, USA)

Background

This workshop was convened by the joint PICES-ISC Working Group on *Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish*, as identified in the Working Group's Terms of Reference (first workshop – PICES-2016). The distribution and productivity of many commercial pelagic fish populations in the North Pacific are determined by large-scale oceanographic processes and climate variability. One hypothesis is that highly migratory pelagic species, such as albacore (*Thunnus alalungus*), have environmental thresholds and preferences that drive their distribution and productivity. The workshop's focus was on statistical modeling approaches that link spatially explicit environmental data (*e.g.*, satellite derived SST) to distributional fish data (*e.g.*, commercial catch per unit effort data, CPUE) for highly migratory species.

List of papers

Oral presentations

Ecology and management of Atlantic bluefin tuna under climate variability and change (Invited)
Barbara A. Muhling, John T. Lamkin, G. Walter Ingram Jr., John F. Walter, Sang-Ki Lee, Yanyun Liu, Ricardo Domingues, Mitchell A. Roffer, Frank E. Muller-Karger, Joseph Quattro and David Lindo Atichati

Population dynamics of fish species in marine ecosystem: A case study in the Bohai Sea, China
Xiujuan Shan, Xianshi Jin, Fangqun Dai, Yunlong Chen, Tao Yang and Jianping Yao

The impact of climate change on Pacific Bluefin (*Thunnus orientalis*) tuna distribution in the Eastern Pacific Ocean
Rosa Runcie, Gerard DiNardo, Toby Garfield, Elliott Hazen, Steven Bograd, Kylie Scales and Jordan DiNardo

Crossing the line: Albacore actively exploit submesoscale fronts to enhance foraging success
Stephanie Snyder, Suzanne Kohin, Yi Xu, Lynne D. Talley and Peter J.S. Franks

PICES-2017
September 22–October 1, 2017, Vladivostok, Russia

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2017

FIS Workshop (W3)

Linking oceanographic conditions to the distribution and productivity of highly migratory species and incorporation into fishery stock assessment models

Co-convenors: *Gerard DiNardo (USA), Carrie Holt (Canada)*

Invited Speaker:
Yong Chen (School of Marine Sciences, the University of Maine, USA)

Background

This workshop was convened by the Joint PICES-ISC Working Group on *Oceanographic Conditions and the Distribution and Productivity of Highly Migratory Fish*, as identified in the Working Group's Terms of Reference. The distribution and productivity of many pelagic fish populations in the North Pacific are determined by largescale oceanographic processes and climate variability. One hypothesis is that highly migratory species, such as albacore tuna (*Thunnus alalungus*) or Pacific sardine (*Sardinops sagax*) have environmental thresholds and preferences that drive their distribution and productivity. The workshop provided an overview of contemporary research on the topic, including the identification of statistical modeling approaches that link spatially explicit environmental data (*e.g.*, satellite derived SST) to distributional fish data (*e.g.*, fishery-dependent and fishery independent), methods to assess impacts of climate variability on fish productivity, and examined methods that explicitly incorporate environmentally driven dynamics into stock assessments for highly migratory species.

List of papers

Oral presentations

Consequences of environmentally driven uncertainty in productivity for management of North Pacific Albacore tuna
Desiree Tommasi, Barbara Muhling, Steven Teo, Gerard Di Nardo

Dynamic ocean management applications for the Drift Gillnet fishery in the California Current
Elliott L. Hazen, Kylie L. Scales, Heather Welch, Dana K. Briscoe, Steven J. Bograd, Heidi Dewar, Suzy Kohin, Scott Benson, Tomo Eguchi, Larry B. Crowder, Rebecca Lewison and Sara Maxwell

Optimal harvest strategies of sandfish based on a stage-structured model in the East Sea
Giphil Cho, Sukgeun Jung, Il Hyo Jung

Differences in biological characteristics of Pacific cod (*Gadus macrocephalus*) between the East and the Yellow Sea, Korea
Kyunghwan Lee, Sukgeun Jung

Individual-based model of chub mackerel (*Scomber japonicus*) covering from larval to adult stages to project climate-driven changes in their spatial distribution in the western North Pacific
Sukgeun Jung

Oceanographic influences on the spawning and recruitment of Pacific bluefin tuna
Barbara A. Muhling, Desiree Tommasi and Gerard DiNardo

Development of methodology for analyses of larval ambient water temperature of Pacific bluefin tuna using SIMS
Yulina V. Hane, Shingo Kimura, Yusuke Yokoyama, Yosuke Miyairi and Takayuki Ushikubo

PICES-2018
October 25–November 4, 2018, Yokohama, Japan

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2018

FIS Topic Session (S12)
Applying ecosystem considerations in science advice for managing highly migratory species

Co-sponsor: ISC

Convenors: *Steve Teo (ISC/USA), Carolina Minte-Vera (IATTC), Gerard DiNardo (PICES/USA)*

Invited Speaker:
Yong Chen (School of Marine Sciences, University of Maine, USA)

Background

Large-scale oceanographic processes and bioenergetic requirements determine the distribution and productivity of many pelagic fish populations in the North Pacific. For example, highly migratory species (HMS), such as albacore tuna (*Thunnus alalungus*) and Pacific sardine (*Sardinops sagax*), have environmental thresholds and preferences, as well as energetic requirements to sustain growth and survival that drive their distribution and productivity. Managing HMS has traditionally focused on maintaining the sustainability of targeted stocks and, as such, comprehensive data sets on the catches, biology and ecology of many exploited stocks exist. In many cases, there are limited quantitative data describing ecosystem impacts on HMS, social and economic impacts on HMS fisheries due to ecosystem variability, and limited formal consideration of the roles of external drivers (*e.g.*, oceanographic variability) in the context of sustainability and governance. Beyond these limitations there is also the challenge to identify linkages and important relationships both within ecosystems (including exploited stocks), and across social, economic and governance facets of fisheries management. This workshop provided an overview of contemporary research on the topic, including the identification of statistical modeling approaches that link spatially explicit environmental data (*e.g.*, satellite derived SST) to distributional fish data (*e.g.*, fishery-dependent and fishery-independent), methods to assess impacts of oceanographic variability on fish productivity and socioeconomic decision making, methodologies that explicitly incorporate environmentally driven dynamics into HMS stock assessments, and challenges facing governance when applying ecosystem considerations.

Summary of presentations

This topic session was convened by WG 34: Joint PICES-ISC Working Group on *Oceanographic Conditions and the Distribution and Productivity of Highly Migratory Fish*. The invited speaker was Yong Chen (University of Maine, USA), who gave a plenary presentation on "Challenge and opportunity for fisheries stock assessment in changing environments". He described how changing

environmental conditions can challenge traditional stock assessment methods, but also described some future paths forward to address some of these issues.

Shingo Kimura described a new method of detecting changes in otolith oxygen stable isotope ratios in Pacific bluefin tuna. The Secondary Ion Mass Spectrometry (SIMS) technique can recreate hindcast potential water temperatures experienced by fish at much higher temporal resolution than previously, including estimation of water temperatures at the time of spawning.

Early career scientist, Ayako Suda, reported on the identification of male-specific DNA markers in Pacific bluefin tuna. A PCR-based method was shown to correctly identify the sex of 131 individual fish, which will contribute to determining optimum sex ratios for aquaculture of this valuable species.

Early career scientist, Kento Nakatsugawa, presented on some apparent spatial changes in the distribution of North Pacific albacore over the last several decades. A westward shift in the distribution of this species may be related to fluctuations in key prey species in the central-western North Pacific, including Japanese sardine and Japanese anchovy.

Barbara Muhling also described results from a study on North Pacific albacore, showing how migration paths in this species may be related to both optimum temperature ranges, and primary production, which can be used as a proxy for foraging conditions. These may also drive some of the latitudinal shifts in albacore off the western North American coast.

Gerard DiNardo presented results of a study led by Desiree Tommasi, on a management strategy evaluation of North Pacific albacore. Simulation results showed how the likelihood of meeting a range of target conditions identified by stakeholders depended on a combination of harvest guidelines, and reference points adopted.

Ning Chen showed estimates of fishing mortality (F), and FMSY for Fang's blenny in Haizou Bay, China, using length-based assessment methods implemented by two different R software packages. The advantages of each package depended on the amount of survey data available to inform them.

Early career scientist, Oxana Mikhaylova, presented on the stock assessment of northern shrimp off Kamchatka, Russia. She described how improving information on the age of the shrimp has allowed several methodological improvements in the assessment over time.

Early career scientist, Xindong Pan, closed the oral session by describing life-history connectivity in Japanese Spanish mackerel from otolith chemistry. Results of his study suggested that immature fish mixed substantially after spawning, and local mackerel assemblages which support fisheries may derive recruitments from multiple geographic locations.

List of papers

Oral presentations

Challenge and opportunity for fisheries stock assessment in changing environments (Plenary)
Yong Chen

Effects of global warming on spawning behavior of the Pacific bluefin tuna based on otolith oxygen stable isotope analysis
Shingo Kimura, Yulina Hane, Yusuke Yokoyama, Yosuke Miyairi, Takayuki Ushikubo and Nobuhiro Ogawa

Development of male-specific DNA markers in the Pacific bluefin tuna (*Thunnus orientalis*): Potential applications for sex ratio control in aquaculture and contribution to tuna resource management
Ayako Suda, Tsubasa Uchino, Issei Nishiki, Yuki Iwasaki, Masashi Sekino, Tetsuya Akita, Nobuaki Suzuki and Atushi Fujiwara

Spatio-temporal distribution of albacore *Thunnus alalunga* and its relationship with environmental changes in the Pacific Ocean
Kento Nakatsugawa, Hidetada Kiyofuji and Shingo Kimura

Migration paths and habitat use of albacore in the eastern North Pacific, with implications for surface fisheries
Barbara Muhling, Desiree Tommasi, Owyn Snodgrass and Heidi Dewar

A management strategy evaluation framework to assess robustness of harvest guidelines for North Pacific Albacore tuna to variable productivity and distribution
Desiree Tommasi, Barbara Muhling Steve Teo and Gerard DiNardo

Evaluating the performance of two methods for estimating fishing mortality rate of Fang's blenny (*Pholis fangi*) based on size frequency data
Ning Chen, Chongliang Zhang, Ming Sun, Binduo Xu, Ying Xue, Yiping Ren and Yong Chen

Commercial stock assessment and forecast of northern shrimp *Pandalus eous* on the south-western Kamchatka
Oxana G. Mikhaylova and Oleg I. Ilyin

Life-history connectivity in a highly migratory fish, Japanese Spanish mackerel (*Scomberomorus niphonius*), implications from otolith chemistry
Xindong Pan, Chi Zhang, Zhenjiang Ye, Binduo Xu, Yang Liu and Yongjun Tian

Poster presentations

Changes in Pacific cod (*Gadus macrocephalus*) size distribution in the North Pacific Ocean over 6 millennia: possible impacts of fishing pressure or environmental variability
Catherine F. West, Michael A. Etnier, Megan A. Partlow, Steven Barbeaux and Alexei Orlov

Variation in the catch rate and distribution of swordtip squid (*Uroteuthis edulis*) associated with factors of the oceanic environment in the southern East China Sea
Jia-Huei Lin, Kuo-Wei Lan and Cheng-Hsin Liao

Review of stock status of Japanese domestic fisheries and new harvest control rule in Japanese domestic fisheries management
Momoko Ichinokawa and Hiroshi Okamura

Role of shallow channel to space -time variation of coastal fisheries resources - Relationship between coastal fisheries resources and oceanographic condition in Hyuga-Nada, Japan
Tsutomu Tokeshi, Kenji Nakanishi and Hirotaka Toyama

Report of Working Group 34
Joint PICES/ISC Working Group on *Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish*

The third meeting of the Joint PICES/ISC Working Group on *Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish* (WG 34) was held from 14:00–17:00 on Sunday, October 28, 2018 in Yokohama, Japan, under the chairmanship of Dr. Gerard DiNardo (USA) and Dr. Chi-Lu Sun (ISC/Chinese Taipei). There were 5 members and 5 observers in attendance (***WG 34 Endnote 1***). The meeting focused on progress and future plans for the working group, including potential topic session proposals for the 2019 meeting to be held in Victoria. Shown below are the agenda items (***WG 34 Endnote 2***), and related notes from the meeting.

AGENDA ITEM 3
Background and progress

Dr. DiNardo gave a presentation summarizing the rationale and background behind the formation of WG 34. The overall aim is to incorporate climate variability into stock assessments and management decision making, via collaborations between scientists from PICES and the ISC. The initial focus of the WG was on North Pacific albacore (see Terms of Reference on WG 34 webpage), but working group activities have since broadened to include other highly migratory species (HMS). Although the WG planned to hold 2 workshops through PICES, and 1 through the ISC, the latter proved too difficult with travel restrictions, and so all meetings have been conducted through PICES. Thus far, two workshops (2016 and 2017), and one topic session (2018) have been held at annual meetings.

Overall, the WG is on track in terms of workshops, but less progress has been made on producing publications. However, some recently published papers will be added to the WG website, and more are in preparation. It is not clear if grey literature publications can be included (*e.g.*, stock assessment and ISC reports). These may constitute a significant portion of the output from the WG, as the Terms of Reference are more management-based. Clarification will be sought from the PICES Secretariat.

AGENDA ITEM 4
Future plans

A one-year extension of the WG has been granted by Governing Council, extending group activities through October 2019. It was agreed that a topic session at the 2019 Annual Meeting in Victoria, Canada, would be a good way to highlight group activities/accomplishments, and a proposal was submitted (see Agenda Item 5). To attract a broader audience, it was suggested that the topic session proposal focus on Ecosystem-Based Fisheries Management (EBFM) for pelagic species generally, potentially with co-sponsorship with S-MBM, as bycatch issues are central to management of many highly migratory species (HMS). The particular difficulty in applying EBFM to HMS was highlighted by stock assessment scientists in attendance, and so the importance of including assessment scientists from multiple agencies (*e.g.*, NOAA, IATTC, NRIFSF) in the 2019 topic session was emphasized. It was agreed that including a panel discussion involving fisheries scientists and managers at the 2019 topic session would be highly beneficial.

AGENDA ITEM 5
Next steps

A proposal for a Topic Session on "*Application of EBFM in the 21st century: progress and challenges in pelagic systems*" (***WG 34 Endnote 3***) at PICES-2019 was submitted for consideration by Science Board. In addition, the potential for a future international symposium on incorporating environmental and climate variability into the management of HMS was discussed. This could be held in the second half of 2020, with potential support from the ISC, PICES and other sponsors. Presentations covering all oceans, and all Regional Fisheries Management Organizations (RFMOs) would be solicited.

WG 34 Endnote 1

WG 34 participation list

Members

Gerard DiNardo (USA, Co-Chair)
Shingo Kimura (Japan)
Barbara Muhling (USA)
Chi-Lu Sun (Chinese Taipei, Co-Chair)
Steve Teo (USA)

Observers

Evan Howell (USA)
Kyung Tae Jung (Korea)
Dr Kim (Chinese Taipei)
Hidetada Kiyofuji (Japan)
Michael Seki (USA)

PICES WG members unable to attend

Canada: Zane Zhang
China: Siqing Chen, Zuozhi Chen, Heng Zhang,
Ping Zhuang
Korea: Youjung Kwon, Sung-Il Lee

WG 34 Endnote 2

WG 34 meeting agenda

1. Welcome
2. Introductions
3. Background and progress (purpose, duration, membership, *etc*.)
4. Future plans: dissolve or extend for another year? Workshop or Session Topic, International Symposium
5. Next steps: Reporting (FIS business mtg., Science Board)
6. Open discussion

WG 34 Endnote 3

Proposal for a Topic Session on "*Application of EBFM in the 21st century: progress and challenges in pelagic systems*" at PICES-2019

Convenors: Barb Muhling (USA, WG 34) Barbara.Muhling@noaa.gov, Gerard DiNardo, USA, gerard.dinardo@noaa.gov

Co-sponsor: ISC

Duration: 1 day

Physical, biological and social components of marine ecosystems interact in complex ways through space and time, resulting in challenges for natural resource managers. Environmental variability and climate change can drive shifts in the spatial distribution and productivity of target and bycatch species, particularly for more mobile pelagic animals. This can impact the effectiveness of stock assessment and management. Ecosystem-Based Fisheries Management (EBFM) aims to address these issues by including environmental effects, species interactions, and other ecosystem-level processes in the management process for exploited species, in addition to fishing pressure. However, despite the theoretical benefits of EBFM, most stock assessments and spatial management measures still use single-species models with no environmental information incorporated.

In this session, we seek presentations describing links between oceanographic processes and management applications in the pelagic environment. Management applications could include the development or modification of stock assessment models, dynamic ocean management rules, bycatch mitigation, multi-species assessments, or other decision processes. Presentations describing opportunities, challenges or lessons learned from EBFM implementation are also welcome. Our session will begin with scientific presentations, followed by a discussion panel of scientists and natural resource managers, which will explore practical aspects of operationalizing EBFM, and promote exchange of ideas between the scientific and management communities.

PICES-2019
October 16–27, 2019, Victoria, Canada

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2019

FIS/POC/BIO/HD Topic Session (S11)
Incorporating ecosystem variability and climate change into fisheries management: Progress and challenges for EBFM in the 21st century

Convenors: *Barb Muhling (USA), Carrie Holt (Canada), Kirstin Holsman (USA), Sukyung Kang (Korea), Gerard DiNardo (USA)*

Invited Speaker:
Stephani Zador (NOAA Fisheries, USA)

Background

Physical, biological and social components of marine ecosystems interact in complex ways through space and time, resulting in challenges for natural resource managers. Environmental variability and climate change can drive shifts in the spatial distribution and productivity of target and bycatch species. This can impact the effectiveness of stock assessment and management. Ecosystem-Based Fisheries Management (EBFM) aims to address these issues by including environmental effects, species interactions, and other ecosystem-level processes in the management process for exploited species, in addition to fishing pressure. Ecosystem variables can be considered qualitatively in management advice by providing context about the state of the ecosystem or quantitatively in models that derive management-relevant quantities (*e.g.*, allowable catch). However, despite the theoretical benefits of EBFM, most stock assessments and management measures still use single-species models with no ecosystem information incorporated. In this session, we sought presentations describing how ecosystem variability and climate change have been considered in management advice qualitatively and/or quantitatively, or on how management advice could consider those variables.

Summary of Presentations

The invited speaker was Stephani Zador (NOAA Fisheries, USA), who gave a presentation on "Merging contextual ecosystem advice with single-species stock assessment to inform fisheries managers in times of extreme environmental changes". She described how ecosystem advice is incorporated into the assessment and management of several fish stocks in the Bering Sea and Gulf of Alaska, both through inclusion in assessment models and provision of contextual advice later in the process. Recent developments in the region included the development of species-specific risk tables, to alert managers and industry to unusual trends or events which could impact stock status or catch limits.

Anne Hollowed presented on the NOAA Climate Fisheries Initiative, which is working on determining the climate information needs of natural resource scientists and managers in United States Large Marine Ecosystems. She described the current implementation plan, and future developments, including the planned adoption of MOM6 for regional downscaling efforts.

Szymon Surma (Early Career Scientist) described a Management Strategy Evaluation (MSE) for Pacific herring in the Northeast Pacific using an ecosystem modeling framework (Ecopath with Ecosim). His results suggested that protected species which feed on herring, such as marine mammals, could benefit most strongly from low allowable catch rates for herring. However, these management actions are predicted to cause frequent closures to the herring fishery, resulting in large economic impacts. The ideal balance between forage fish protection and sustainable herring fisheries was thus difficult to achieve.

Isaac Kaplan presented research testing the performance of different stock assessments from the California Current and Nordic/Barents Sea under climate change conditions, using Atlantis ecosystem models. Stock assessment performance was evaluated by quantifying the bias and precision of derived quantities related to population size, fishing intensity, and depletion, and by evaluating management performance when fishing rates were set based on reference points estimated in the assessments.

Gloria Duran (Early Career Scientist) showed how the catch per unit effort of swordfish on longline gear was influenced by oceanographic features in the Kuroshio Extension system. Her results highlighted the importance of mesoscale eddies, as well as Kuroshio Current instability, in driving spatial distributions of catch rates.

Phoebe Woodworth-Jefcoats presented a number of different ways by which EBFM could be better incorporated into the deep-set longline fishery targeting bigeye tuna in the central and eastern North Pacific. Current management measures can cause a “race to fish”, leading to instability in prices and profits for fishers. Alternative management strategies could ameliorate these issues, as well as providing ways to address potential future yield decreases in the region under climate change.

James Smith presented the results of a simulation study, looking at the effects of different spatial closures in the west coast US drift gillnet fishery. Dynamic spatial closures can provide more economic opportunity for fishers than static closures, but can also lead to potentially higher rates of turtle interactions. The low number of turtle observations available for building species distribution models was identified as a key uncertainty in the study.

Yan-Lun Wu described how global yellowfin tuna catch rates are correlated with a suite of climate indices across different ocean basins. Wavelet analysis showed that basin-specific indices (*e.g.*, Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation) were generally most influential in the region over which they are calculated, but they could also be important in neighboring basins.

Johanna Wren (Early Career Scientist) presented a network analysis for the Hawaii-based deep set longline fishery. This work used co-occurrence measures to show associations between target species (bigeye tuna) and various bycatch species. These associations were often stable through time, but varied across the spatial extent of the fishery.

Desiree Tommasi showed results from a study predicting Pacific bluefin tuna recruitment based on surface temperatures around nursery areas in the western North Pacific. She showed that multiannual forecasts of SST had some potential to predict recruitment in advance, but that more work is required to capture the observed variability in interannual recruitment for this species.

Melissa Karp (Early Career Scientist) presented recommendations from a recent workshop on the impacts of shifting distributions and productivity changes in managed stocks for the United States. She highlighted the importance of continuing survey data collection, appropriate modeling techniques, and communication with management agencies in addressing these issues.

Fan Zhang (Early Career Scientist) examined the presence of hysteresis and alternative stable states in populations of cod and American plaice in the Northwest Atlantic. He showed that hysteresis did exist in time series of abundance for these two species, but that these regime shifts did not appear to be predictable in advance using time series characteristics such as temporal autocorrelation and variance through time.

Kristin Marshall described work from the western United States examining the robustness of Pacific hake management strategies to environmental variability. Her results suggested that status quo management may lead to reduced management performance if hake distributions shift in the future, due to climate change.

Elliott Hazen presented work on behalf of Heather Welch describing how surface temperature metrics in the Southern California Bight can reduce bycatch of loggerhead turtles on fishing gear. This study found that a 6-month mean of surface temperature was the best indicator of turtle presence on the fishing grounds, and that turtles were more likely to be encountered when temperatures were anomalously high.

Briana Abrahms (Early Career Scientist) showed how ship strike risk for blue whales off southern California was predictable based on suitable foraging habitat for whales, and locations of shipping lanes. A dynamic ocean management strategy was shown to have potential advantages over a current voluntary ship speed limit imposed from spring through fall.

Johanna Wren presented work on behalf of Donald Kobayashi describing a climate vulnerability assessment for marine species in the Pacific Islands region. Vulnerability to future climate change varied widely depending on the habitat of each species, with sharks showing potentially high vulnerability out of the more than 80 species considered.

Carrie Holt described the results of a review examining how environmental information is incorporated into stock assessments and management decisions for Canadian fisheries. She showed that the incorporation of environmental metrics is most common at the hypothesis development stage, and as qualitative information during the assessment process, but is less commonly included when giving management advice.

James Thorson described how the decomposition of environmental drivers into large-scale indices, and local effects, can best represent the impacts of environmental regimes on species distribution shifts. He also showed how spatiotemporal aucotcorrelation frameworks can be useful to address gaps in survey sampling designs through time.

Yumeng Pang (Early Career Scientist) presented work examining the effects of temperature on the reproductive characteristics of two commercially important squid species. These were shown to be potential drivers behind observed changes in stock biomass through time, which have impact fisheries landings in the region.

Xiutang Yuan described the results of laboratory studies on impacts of warming and acidification on a species of sea cucumber. His work showed that this species attained larger sizes at warmer water temperatures, but that acidification negatively impacted growth.

Brian Wells presented results from a life cycle model for eastern Pacific salmon. This work highlighted the importance of predation to juvenile salmon survival during the marine part of their life history, as well as the impacts of juvenile size upon emigration from freshwater environments.

Barbara Muhling described historical changes in the distribution of eastern North Pacific albacore fisheries in the past several decades. Her results suggested that future climate change may have complex effects on albacore distribution, and that drivers of inshore-offshore shifts in the fishery need to be better understood.

Desiree Tommasi presented work on behalf of Kisei Tanaka, showing the skill of temperature forecasts for estimating species distribution shifts in the Northwest Atlantic. Forecasts at 1- to 5-year lead times showed particular promise for future predictions.

Tatiana Kozlova described the dynamics of pink salmon abundance in riverine environments in coastal Russia. Her work suggested that environmental drivers were strongly influential in determining salmon dynamics, and thus availability to fisheries.

List of papers

Oral presentations

Merging contextual ecosystem advice with single-species stock assessment to inform fisheries managers in times of extreme environmental changes (Invited)
Stephani Zador, Elizabeth Siddon and Martin Dorn

National Oceanic and Atmospheric Administration's Climate Fisheries Initiative: Long-term projections
Anne B. Hollowed, Charles Stock, Alan Haynie, Albert Hermann and Kirstin Holsman

Towards ecosystem-based management of Northeast Pacific herring fisheries
Szymon Surma

Fragile ecosystems, robust assessments? Performance testing stock assessments for the California Current and Nordic and Barents Seas under climate change
Isaac C. Kaplan, Sarah K. Gaichas, Patrick D. Lynch, Christine C. Stawitz and Cecilie Hansen

Spatiotemporal interannual variabilities of swordfish catch in relation to fronts and eddies in the northwestern Pacific
Gloria S. Duran, Takeyoshi Nagai and Kotaro Yokawa

Ideas on how to incorporate EBFM into a pelagic longline tuna fishery
Phoebe A. Woodworth-Jefcoats, Justin Hospital, Johanna L.K. Wren, and Sarah Medoff-Wong

An evaluation of dynamic and static spatial management in a swordfish fishery: Balancing economic and bycatch concerns
James A. Smith, Desiree Tommasi, Michael Jacox, Elliot Hazen, Heather Welch and Stephanie Brodie

Application of time series analysis to detect the effect of multi-scale climate indices on global yellowfin tuna population
Yan-Lun Wu, Kuo-Wei Lan and Yong-Jun Tian

Network analysis in the Hawai'i-based longline fishery reveal spatiotemporal changes in network complexity and species association from 1995-2019
Johanna L.K. Wren and Phoebe A. Woodworth-Jefcoats

Integration of multiannual climate predictions in the estimation of stock status and rebuilding time frames for highly migratory species
Desiree Tommasi and Barbara Muhling

Accounting for shifting distributions and changing productivity in U.S. marine fisheries management: challenges and recommendations
Melissa Karp, Jay Peterson, Patrick Lynch and Roger Griffis

Regime shift and early warning signals of Atlantic cod and American plaice on Grand Bank off Newfoundland
Fan Zhang, Paul Regular and Eric Pedersen

A multi-model approach to better understanding the robustness of management of Pacific hake to environmental variability
Kristin N. Marshall, Isaac C. Kaplan, Kirstin Holsman, Grant Adams and Nis Jacobsen

Environmental indicators to reduce loggerhead turtle bycatch offshore of Southern California
Heather Welch, Elliott L. Hazen (presenter), Dana K. Briscoe, Steven J. Bograd, Michael G. Jacox, Tomoharu Eguchi, Scott R. Benson, Christina C. Fahy, Toby Garfield, Dale Robinson, Jeffrey A. Seminoff and Helen Bailey

The only constant is change: Incorporating socioecological variability into protected species management
Briana Abrahms, Hannah Blondin, Steven J. Bograd, Blake Feist, Mary Fisher, Arjun Hausner, Elliott L. Hazen, Jameal Samhouri

Assessing the vulnerability of marine life to climate change in the Pacific Islands region
Donald R. Kobayashi, Jonatha Giddens, Mark Nelson and Johanna Wren (presenter)

Incorporating climate, oceanographic and ecological change considerations into population assessments in Canada: A review and recommendations
Pierre Pepin, Jacquie King, Carrie Holt, Helen Gurney-Smith, Nancy Shackell, Kevin Hedges and Alida Bundy

Measuring the impact of oceanographic indices on species distribution shifts: The spatially varying effect of cold-pool extent in the eastern Bering Sea
James T. Thorson

Environmental effects on reproductive traits in cold/warm-water squids: implications on catch fluctuation
Yumeng Pang, Chin-Shin Chen, Tomohiko Kawamura and Yoko Iwata

Impact of seawater acidification and warming on the early development of the sea cucumber *Apostichopus japonicus* (Selenka) (Echinodermata: Holothuroidea)
Xiutang Yuan, Mingshan Song, Xiaolong Yang, Anguo Zhang and Lili Wang

Environmental determinants of spatiotemporal variability in salmon forage and its direct and indirect effects on salmon recruitment
Brian K. Wells, Whitney R. Friedman and Megan Sabal

Shifting distributions of fisheries for juvenile albacore in the eastern North Pacific
Barbara Muhling and Desiree Tommasi

Prospects for environmental prediction of annual fishery range expansion and contraction: a case study in the Northwest Atlantic
Kisei R. Tanaka, Fernando G. Taboada, Charles A. Stock, Desiree Tommasi (presenter), Malin L. Pinsky, Vincent S. Saba and Jorge L. Sarmiento

Dynamics of pink salmon (*Oncorhynchus gorbuscha*) abundance in the Tatar Strait rivers (Sea of Japan)
A.A. Dulenin and Tatiana V. Kozlova

Poster presentations

Is there a disruption in the food-web pathways in the Strait of Georgia that might be related to the declines in the Pacific salmon and Pacific herring in Canada?
David Costalago, Brian P.V. Hunt, Chrys Neville, Ian Perry, Kelly Young and Ian Forster

Traditional intertidal species regression study
Mikale Milne and Amy Cline