Contribution to the round of informal consultations on General Assembly Resolution 78/68 on the topic "Sustainable Fisheries Management in the face of climate change" by the North Pacific Marine Science Organization (PICES).

Prepared by PICES Secretariat (Sonia Batten, Executive Secretary and Sanae Chiba, Deputy Executive Secretary) based on contributions from PICES Expert Groups.

> The North Pacific Marine Science Organization (PICES) is an intergovernmental science organization, rather than a Regional Fisheries Management Organization, but it partners with the Commissions with whom it shares an area of interest (both geographic and scientific) in order to coordinate and integrate research from the climatic, physical and biological foundations of the ocean system to the dynamics of higher trophic levels, including fisheries and human communities. These partnerships enable PICES to provide the scientific basis for policy decisions that the RFMOs and national agencies must determine, and to receive input on the science and information needs that are required for effective and sustainable resource management. Climate change and its impacts on the processes and ecosystems of the North Pacific is, of course, a current priority area of focus with many PICES events and expert groups incorporating climate change research and concerns into their activities.

Below is a summary of the recent findings by PICES expert groups under the relevant categories requested by DOALOS, with references to publications where more detailed information can be found, if required.

Experience in sustainable fisheries management in the face of climate change, including in relation to:

a. Assessing the impacts of climate change in fisheries

1. The *Joint PICES/ISC (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean) Working Group on Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish, WG34*, found that significant progress was been made in the four years of its life-span (to 2020) on understanding habitat use of highly migratory species in the North Pacific, particularly with respect to albacore and Pacific bluefin tuna. Research results highlighted the important roles of species-specific thermal limits in determining foraging areas and migratory corridors. There was also some evidence that changes in the distributions of prey fields can have substantial impacts on the distribution of HMS (highly migratory species), 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 2015–2016 marine heatwave.

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, or electronic monitoring systems, such as vessel monitoring systems. In some cases, observations from fishery-independent surveys are available which may also include life stages not present in commercial or recreational fishing data. However, at-sea surveys are expensive and time-consuming to run, particularly for species which are found across very large spatial areas. As a result, the majority of data available for modeling HMS distributions comes from the fishing industry. 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 mostly focused on the geographic ranges covered by national fishing fleets, rather than attempting to combine data from different countries. 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.

<table>
<tr><td colspan="2">Joint PICES/ISC Working Group on Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish, WG34</td></tr>
<tr><th>Key outputs</th><th>Relevant references</th></tr>
<tr><td>Developed environmentally-informed species distribution models for Pacific bluefin tuna and albacore in the North Pacific Ocean
Developed future projections of albacore distribution in the eastern North Pacific using climate model outputs
Explored predictability of recruitment from ocean conditions and climate variables for Pacific bluefin tuna and albacore.
Contributed to development of international Management Strategy Evaluation (MSE) for North Pacific albacore.
Convened workshops and topic sessions at PICES annual meetings to promote international collaboration and information sharing</td><td>Working Group report Rpt61.pdf (pices.int)

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

Runcie, R.M., Muhling, B. A., Hazen, E.L., Bograd, S.J., Garfield, T. and DiNardo, G. 2019. Environmental associations of Pacific bluefin tuna (Thunnus orientalis) catch in the California Current system. Fisheries Oceanography 28: 372–388, https://doi.org/10.1111/fog.12418.

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.</td></tr>
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2. The *Joint PICES/ICES (International Council for Exploration of the Seas) working group on Impacts of Warming on Growth Rates and Fisheries Yields, WG45*, is a still-active expert group expected to complete its term later in 2024. A session was convened by the working group at the 2022 ICES Annual Science Conference and concluded that despite the theoretical predictions of the Temperature Size Rule on how temperature affects body size (the TSR proposes that fish living at warmer temperatures will have rapid early growth but lower adult size according to Forster et al. 2012), many presentations showed observations indicating that responses in natural populations can be more complex, and that other factors such as fishing and food availability must be appropriately considered. The session highlighted that there are still large disagreements in the underlying mechanisms of temperature impacts on fish size in natural ecosystems. It did, however, reinforce that: temperature does have strong impacts on fish populations (directly or indirectly); careful experimentation and analysis of fisheries data offers exciting opportunities to test new theoretical models; and, concerted effort is urgently needed to appropriately consider temperature effects in fisheries models.

   Other findings to date are summarized here:

Joint PICES/ICES Working Group Impacts of Warming on Growth Rates and Fisheries Yields, WG45	
Key outputs	**Relevant references**
• Fish sizes are declining in several regions including the western North Pacific. The fish weight of many stocks decreased during the 2010s because of severe competition under climate-induced lower productivity of planktonic prey. • Multiple state-space models were developed and applied to size-at-age of groundfish in the California Current system, and revealed different information on size-at-age patterns. A von Bertalanffy state-space model indicated that inclusion of temperature effects on growth during the first year of life improved model performance for all 7 species examined. Additionally, a state-space autoregressive length-at-age model was developed (SARLA; http://github.com/wggrafy/sarla) indicated that variability in size-at-age can be partitioned into cohort, annual, and initial-size effects, although there were not similarities in the direction of growth responses between species.	Lin and Ito (2024) Fish weight reduction in response to intra- and interspecies competition under climate change. Fish and Fisheries. Doi: 10.1111/faf.12818

b. Addressing the impacts of climate change on fisheries

The PICES program *FUTURE (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems)* is an integrative Scientific Program undertaken by the member nations and affiliates of PICES to understand how marine ecosystems in the North Pacific respond to climate change and human activities, to forecast ecosystem status based on a contemporary understanding of how nature functions, and to communicate new insights to its members, governments, stakeholders and the public.

One of the significant outputs of FUTURE to date has been to explicitly identify the climate system, and its effects on the physico–chemical ocean environment, as necessary to fully understand current changes taking place within the North Pacific, and express this as a coupled social–ecological–environmental system (SEES). The paper below (Bograd et al., 2019) contains details of how PICES has implemented a SEES framework in the North Pacific to facilitate bridging between local communities and basin scale dynamics, and to better understand complex dynamics that impact its coastal communities. The SEES concept was applied to four case studies in the North Pacific to demonstrate its utility. Two studies are summarized here as examples:

1. *Alternation of Japanese sardine and chub mackerel populations in the Western Pacific*. Purse seiners and local communities suffered economic losses from the collapse of the Japanese sardine stock in the late 1980s to the mid 1990s. Purse seiners switched their target catch to immature chub mackerel eventually leading to the overfishing of this stock in the 1990s. The government of Japan and the purse seiners cooperatively introduced a management plan and since its adoption, the stock of chub mackerel has increased and the well being of coastal communities improved. An increased understanding of the dynamics associated with these alternations, from climate regime shifts to fisher behavior and the effects of both governmental and industry interventions, provides an important basis for understanding future changes. Continued monitoring of the physical (environmental) conditions, plankton production and phenology, and larval fish survival in this region will be essential to identify ecosystem change and inform adaptive management strategies for coastal fishers.
2. *Ecosystem Impact of a Marine Heat Wave in the Eastern Pacific*. The northeast Pacific Ocean experienced highly anomalous atmospheric and oceanic conditions during 2014–2016, which was accompanied by significant ecosystem disruptions along the North American West coast. One outcome, a wide-spread toxic algal bloom, led to the closure of salmon fisheries and changes in the timing of crab fisheries. These actions caused disproportionate negative economic impacts on small scale fishers, as well as an unfortunate temporal and spatial overlap in foraging whales and delayed crab fisheries which increased whale entanglement in fishing gear. Important, and relatively rapid, management actions took place in response which likely mitigated some of the more negative impacts. Fishers made requests for a disaster declaration resulting in committees of managers, scientists, fishers and NGO representatives to develop adaptive management strategies that included changes in marine spatial planning and funds to the fishing community to pay for removal of derelict fishing gear. However, with extreme events likely to become more frequent with climate change a SEES approach, and monitoring of environmental and ecosystem conditions, can confer resiliency to the human communities that depend on the sea.

FUTURE Science Program	
Key outputs	**Relevant references**
• Applied a Social-Environmental-Ecological Systems (SEES) framework to integrate trans-disciplinary knowledge across PICES Expert Groups to 4 crisis case studies in the North Pacific, including climate-driven changes in species distributions and abundances as well as multiple stressors (marine heat waves, harmful algal blooms, etc.)	Bograd, S.J., Kang, S., Di Lorenzo, E., Horii, T., Katugin, O.N., King, J.R., Lobanov, V.B., Makino, M., Na, G., Perry, R.I. and Qiao, F., 2019. Developing a social–ecological–environmental system framework to address climate change impacts in the North Pacific. Frontiers in Marine Science,

• Species alternation in the Western Pacific • Ecosystem impact of marine heat waves in the Eastern Pacific • Jellyfish blooms in the Western Pacific • Warming and distributional shifts in highly migratory species • The SEES approach can strengthen communication pathways and focus limited resources on shared problems.	6, p.333. https://doi.org/10.3389/fmars.2019.00333

c. Accounting for cumulative impacts

The FUTURE program provides, as an example here, that direct and indirect cumulative effects of anthropogenic pressures on salmon- and herring-linked land and ocean ecosystems in the Northeast Pacific were investigated and showed the need for a land to ocean integrated management approach: Tulloch, V. JD, et al. "Accounting for direct and indirect cumulative effects of anthropogenic pressures on salmon-and herring-linked land and ocean ecosystems." Philosophical Transactions of the Royal Society B 377.1854 (2022):DOI:10.1098/rstb.2021.0130

d. Application of an ecosystem approach and the precautionary approach in the face of climate change.

N/A. PICES does not have management responsibilities or tools.

e. Incorporating economic, social and cultural aspects into sustainable fisheries management in the face of climate change.

The PICES Working Group on Marine Ecosystem Services (WG41) recently completed its term and is working on a scientific publication as a final product which will be released later in 2024. Ocean ecosystems provide direct, and indirect, benefits to human populations through ecological goods and services (seafood, recreation and leisure opportunities, and biodiversity maintenance, among others). The accounting for anthropogenic values of marine ecosystem services (MES) in policy and management decisions has become an emergent issue recognized as critical from a social, economic, and cultural perspective, but also one that poses challenges both from a scientific and policy perspective.

WG on Marine Ecosystem Services	
Key outputs	**Relevant references**
• Examined the concept and classification of marine ecosystem services • Reviewed and assessed the methods for measuring them from ecological,	• Lew, D.K. "Marine Ecosystem Services: Concepts and Classifications" (Forthcoming) Chapter 1 in PICES Scientific Report, "Marine Ecosystem Services in the North Pacific," Lew, Magnusson, and Ray (eds.).

economic, and sociocultural disciplinary perspectives	• Lew, D.K., Leong, K., Dudas, S.E., Cox, K., Nakachi, A., Ingram, R., and Fisk, J. "Assessing Marine Ecosystem Services in the North Pacific: An Overview of Approaches" (Forthcoming) Chapter 2 in PICES Scientific Report, "Marine Ecosystem Services in the North Pacific," Lew, Magnusson, and Ray (eds.).

The examples of social–ecological–environmental systems (SEES) given above in Section b. are also relevant here and will be further explored in a new expert group, established recently to examine the impacts of climate extremes on coastal communities around the Pacific Rim, which are highly reliant on coastal ecosystem services. Such communities are particularly vulnerable to these extreme events and in need of a suite of potential solutions to these climate-driven changes.

Lessons learned, best practices and challenges in sustainable fisheries management in the face of climate change

Key messages	Relevant references
• Physiological mechanisms driving observed patters of species distributions and movements should be a focus, instead of relying on correlative relation ships. • Improve communication between scientific community, population dynamics and stock assessment communities • In order to predict near-term and long-term future changes in recruitment of North Pacific Highly Migratory Species, improved mechanistic understanding of spawning and larval ecology will likely be required. • 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.	Barbara Muhling and Siqing Chen (Eds.) 2020. Report of PICES/ISC Working Group 34 on Ocean Conditions and the Distribution and Productivity of Highly Migratory Fish. Rpt61.pdf (pices.int)
• A trans-disciplinary approach is critical to understand how climate impacts are integrated through marine ecosystems and coastal communities • Sustainable fisheries management requires an assessment of multiple and cumulative stressors • End-to-end modeling infrastructure (climate-ecological-social) is essential for understanding the mechanisms by which climate change impacts fisheries, and for developing management strategies	

• Surveys of ocean managers and decision-makers were conducted in China, Canada, and the U.S. to evaluate the extent to which marine ecosystem service values were or could be useful for fisheries management and analyses involving climate change effects. • A majority of respondents found ecosystem service value information helpful or useful for fisheries management analyses and decision-making, but differences were seen in how this information is viewed in China compared to the U.S. and Canada.	Magnusson, G.M., Wallmo, K., Li, J-M, Brewer, J., Lew, D.K., Su, M., Shan, J-Z, and Wang, N. "Perceptions and Use of Marine Ecosystem Service Values in Decision-Making in Three PICES Countries: Canada, China, and the United States of America (USA), Chapter 4 in PICES Scientific Report (Forthcoming), "Marine Ecosystem Services in the North Pacific," Lew, Magnusson, and Ray (eds.)

Actions needed to further strengthen sustainable fisheries management in the face of climate change, including to address particular challenges faced by developing countries through capacity-building.

- Define habitat and movements of Highly Migratory Species throughout their geographic ranges, and across different life stages will be most effectively achieved if fishery-dependent and fishery-independent datasets from different countries can be analyzed together. 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.
- Further development of end-to-end modeling infrastructure, including Management Strategy Evaluations.
- Development of global networks to facilitate the transfer of knowledge and capacity, including data and tools.
- Training in interdisciplinary science and ecosystem-based management.
- Capacity development of local small-scale fishers and communities to monitor their coastal ecosystems and coastal fisheries (for example using a smartphone app) to benefit human health in Pacific rim developing countries is an example of capacity development undertaken by PICES in collaboration with the Japanese Government (see for example: Ciguatera) and could be expanded.