Towards an integrated approach to understanding ecosystem predictability in the North Pacific

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Efforts to predict physical climate and ocean conditions that are relevant for ecosystem dynamics have developed independently across the PICES community, but the skill and utility of these predictions for ecosystem applications has been poorly quantified. By discussing and inter-comparing the various efforts, including the methods used to make predictions, their specific applications and user groups, as well as the dynamical mechanisms responsible for predictability, members of PICES Working Group 40 (WG-40) on Climate and Ecosystem Predictability hope to improve the ability to translate scientific understanding into information that can facilitate improved resource management and societal action.

In June, the working group met at the First Institute of Oceanography (FIO) in Qingdao, China for a two-and-a-half-day intersessional workshop at the invitation of Dr. Fangli Qiao. The main objective of WG-40 is "to identify, diagnose and quantify predictable responses in North Pacific marine ecosystems that arise from regional- and large-scale climate processes". The goals of the intersessional workshop were to review some of the current ecosystem forecasting efforts, assess the mechanisms responsible for predictability in the different areas, and discuss the steps and action required to develop a common and integrated framework for forecasting activities. The International CLIVAR Program Office endorsed the objectives of the workshop, and several members from the program office attended the meeting. There is mutual agreement that continued collaboration between the two communities is desired, as it provides the basis for a very important, societally-relevant and inter-disciplinary endeavor. In that spirit, the CLIVAR Pacific Region Panel is planning to attend the PICES Annual Meeting in Victoria to meet jointly with WG-40. In addition to PICES representatives and members of the International CLIVAR Program Office, several early career scientists from local institutions (FIO, Xiamen University, the Institute of Oceanography of the Chinese Academy of sciences, and the Yellow Sea Fisheries Research Institute) joined the discussion.

At this workshop, several of the participants provided brief introductions to the forecasting systems or mechanisms of predictability they were most familiar with. To create an overarching context for the discussion, Dr. Shoshiro Minobe outlined the different atmosphere and oceanographic processes that facilitate predictability in the western North Pacific, highlighting, in particular, the stratosphere-troposphere coupling and its influence on the Arctic Oscillation and the possible relevance of the 18.6-year tidal modulation. Workshop participants agreed that a list of the processes responsible for predictability of physical climate and marine ecosystems in the different PICES regions would be developed and shared.

Leading off the discussion of predictions and predictability in the eastern North Pacific, Dr. Ryan Rykaczewski described how coarsely resolved global models indicate that anomalous mixing in the western and central portions of the basin can produce anomalies in nitrate and oxygen that persist for years to decades and are slowly advected to the eastern side of the basin by the mean ocean circulation. This slow advection timescale, combined with in situ observations could be exploited for predictions of eastern North Pacific biogeochemical anomalies years to a decade into the future. This mechanism and its potential for enhanced predictability will be further explored.

High-resolution regional models are key tools for physical and ecological predictions in coastal regions. Such regional models, however, require the prescription of lateral boundary conditions and surface forcing that are usually obtained from global coarser resolution climate models. "Downscaling" the coarse

climate information to the much finer regional grid is in itself a research effort. Dr. Pozo Buil reported on a downscaling effort that focused on the California Current System. She showed that applying a combined statistical and dynamical downscaling method leads to improved representation of relevant ecosystem variables like sea-surface temperature. She also showed that the predictability in higher-trophic-level properties (i.e., species distribution) is consistent with predictable temporal components (i.e., climatology and low frequency) of the physical parameters.

While general circulation models are typically used for predicting future marine conditions, empirical dynamical models like Linear Inverse Models (LIMs) have shown a skill comparable to that of state-of-the-art operational prediction systems in the tropical Pacific. However, their performance in regions outside the tropical Pacific has been less investigated. Dr. Antonietta Capotondi presented an application of the LIM approach over the tropical and North Pacific regions to examine the predictability of the extreme and persistent warming (Marine Heat Wave) that occurred in the northeast Pacific from the winter of 2013/14 to the winter on 2015/17. The LIM can also be run for a very long (O(100000 years)) time to construct robust statistics of sea-surface temperature and sea-surface height (a quantity related to thermocline depth and upwelling), in the northeast Pacific and establish the degree to which individual events, like those in 2014-2015, may be seen as "unusual" and extreme. Such application will be considered in the near future.

To finish the examples of prediction efforts in the eastern North Pacific, Dr. Caihong Fu presented a talk on marine ecosystem modeling to simulate species biological responses to environmental changes and management strategies. Such a modeling platform has the potential to address multiple stressors in marine ecosystems, including climate-induced environmental changes and over-exploitation of commercial fish species, and to project future states of marine ecosystems under future changes of climate and management strategies.

Participants with expertise in the western North Pacific shared their experience with prediction efforts, ranging from global models that explore predictability in basin properties (on timescales of several years) to models that focus on predicting the presence of harmful algae (on the scale of a few days). Dr. Fei Chai described his efforts to enhance the biogeochemical Argo network and the subsequent production of short-term forecasts of nutrients, oxygen and carbon cycle for the Northwest Pacific and China Seas. Dr. Shoshiro Minobe reported on a large multivariate analysis effort using data of marine ecosystem indices from both sides of the North Pacific basin for the last half century. He noted that the first mode of variability in these indices is common between the western and eastern sides of the basin, but the second mode exhibit substantial differences between the two regions.

Dr. Masami Nonaka introduced JAMSTEC's seasonal climate prediction activities that have been conducted for more than ten years, focusing on the skill of this effort in the western North Pacific region. Also, potential predictability of eddy activities in the Kuroshio Extension region was discussed based on an eddy-resolving ensemble simulation. Eddy activities in the downstream part of the region are suggested to have some deterministic and predictable component.

Prediction of the living components of marine ecosystems are just as critical as predicting anomalies in ocean and atmosphere physical properties. Dr. Yongjun Tian described the use of long-term time series of fisheries landings, climate, and oceanographic data, to examine patterns of variability in small pelagic species and fish community structures in three current systems around Japan and the China Seas. Low-frequency variability in the fish communities of the northwestern North Pacific was evident and displayed

good correspondence with climate change metrics. Applying such relationships to current climate observations may foster predictability for some small pelagic species.

Dr. Zengrui Rong provided a captivating example of the real-world application of marine predictions, describing how satellite observations combined with a hydrodynamic model is used to predict the advection of the "green tide", a green algae that affects Qingdao and the Shandong Province in China. The capability of the forecasting system to predict the distribution and trajectory of the green tide has been evaluated, and it appears to perform well over a time scale of about 10 days.

The host of the workshop, Dr. Fangli Qiao, reported on the hindcast and seasonal prediction results derived from the FIO climate model (FIO-ESM V1.0). The seasonal prediction skill in the North Pacific has been much improved by including surface wave-induced vertical mixing in the ocean model component, allowing the possibility to provide operational seasonal prediction products for PICES member states. In particular, the bias between the observed and modeled sea-surface temperature decreases substantially in the transition zone between the subarctic and subtropical gyres in the North Pacific, and sea-surface temperature variability can be successfully hindcasted in the climate model when the surface wave component is included.

Dr. Xuehai Liu introduced a systematic coastal ecology-sediment-environment coupled numerical model and its utilization for the South Yellow Sea and aquaculture bays. In particular, the model has been used to investigate the results of the spring bloom and the role of wave-induced mixing, the effect of sediment on biomass in shoal areas, physical-biochemical effects of aquaculture, the aquaculture carrying capacity, and the possibility of phytoremediation in eutrophic waters.

To conclude the examples of forecasting efforts, Dr. Liping Yin described the physical factors that influence the artificial stock enhancement for the edible jellyfish in Liaodong Bay, China. The resource of the wild edible jellyfish in China has declined in the last decades and artificial releasing has started becoming an important approach to keep its yield.

Workshop participants were impressed by the diversity of prediction approaches, the need and utility of the predictions, and the existence of several mechanisms that facilitate these predictions. To better understand the range of efforts, working group members agreed to continue the development of an inventory of forecasting efforts in the North Pacific along with a list of the mechanisms that impart predictability. A journal special issue or section will be developed based on the workshop presentations and on the contributions to the session "Advances in North Pacific marine ecosystem prediction", which has been organized by members of WG-40 at the 2019 PICES Annual Meeting.

Coordinated predictions experiments of key North Pacific variables would provide an opportunity for an insightful inter-comparison of the different prediction approaches and their respective skill in different applications. Participants agreed that, as a starting point, few key properties of North Pacific climate should be considered, and developed a preliminary, prioritized list of these properties. The working group hopes that by highlighting the predictability (or lack thereof) of key North Pacific quantities, the PICES community can work to improve predictions of those quantities and their use in the management of marine resources.

In addition to the group's scientific discussions, Dr. Fanqli Qiao arranged visits of many of the facilities of the FIO. Workshop participants were treated to tours of the China Ocean Exploration Museum, the FIO

high-performance computing facility, and the State Oceanic Administration's R/V Xiang Yang Hong 18 ship. These visits were a great way to cap off a very productive and enjoyable intersessional workshop.