# OSM Workshop on "*Top predators as indicators of climate change: Statistical techniques, challenges and opportunities*"

*by Elliott Hazen, Rob Suryan, Takashi Yamamoto and Steven Bograd*

Top predators such as fish, turtles, marine mammals, and seabirds integrate multiple lower trophic level processes and can also exert top-down control of marine food webs. Climate change and variability affect the timing and productivity of pelagic ecosystems. This variability is integrated into the life histories of top predators, potentially affecting their breeding patterns, migration strategies, diets, and ultimately, fitness and reproductive success. Pan-Pacific data about top predators are generated by surveys, animal tracking studies, dietary analyses, and measurements of reproductive performance. Environmental and climate data can be synthesized and compared to ecosystem responses in many locations. To incorporate top predators into our understanding of climate change impacts on marine ecosystems and to support the objectives of FUTURE, the PICES Advisory Panel on *Marine Birds and Mammals* (AP-MBM) with joint support from IMBER's regional program, CLIOTOP (Climate Impacts on Oceanic Top Predators), convened this workshop to examine how top predators have responded, and are predicted to respond, to climatic variability and long term change.

The primary goal of this workshop (W1) was to review existing examples of observed and predicted top predator responses to climate change and variability in the North Pacific. More specifically, we had a number of goals that came to light via talks and workshop discussions:

- Identify existing top predator, ecological, and oceanographic datasets that can be used to examine response to climate variability and change;
- Review statistical techniques that can be used to differentiate top predator response from climate variability and change;
- Identify sentinel species and life history characteristics that may best reveal responses to physical and biological changes;
- Discuss synthetic approaches, beyond single measurement types, that are needed to understand how climate variability and change is integrated by top predator behavior, distribution, abundance, and demography;
- Prepare a statement outlining the need for enhanced sampling for top predator response to the predicted 2014–2015 El Niño event;
- Outline and write a review paper on a framework for assessing climate response in North Pacific top predators
- Realize the goal of an interdisciplinary, North Pacific-wide funding proposal to synthesize top predator datasets relative to potential climate change effects;
- Continue these efforts in collaboration with CLIOTOP and IMBER at the 3rd PICES/ICES Symposium on the "*Effects of climate change on the world's oceans*" in 2015.

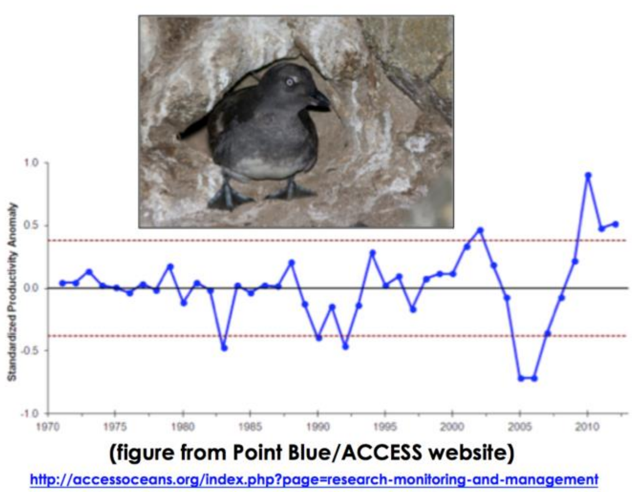
With the primary goal of FUTURE, "*To understand and forecast responses of North Pacific marine ecosystems to climate change and human activities at basin and regional scales, and to broadly communicate this scientific information to members, governments, resource managers, stakeholders and the public*", top predators are particularly useful given their integration across the physical environment and multiple trophic levels, making their responses a metric of ecosystem change. Also, there is strong public interest in many top predators, making outreach and engagement easier than for other ecosystem components. Furthermore, a wide variety of data has been collected on top predators, including multiple responses (behavior, distribution, fitness) to climatic events (*e.g.*, El Niños) that may give us insight to future long-term changes.

*Participants of the top predators workshop.*

There were 22 participants in the workshop. The workshop included 4 invited talks, 7 contributed talks, and 2 hours of discussion. The talks were organized largely by species groups, starting with fish predictions as a function of climate change and finishing with baleen whales.

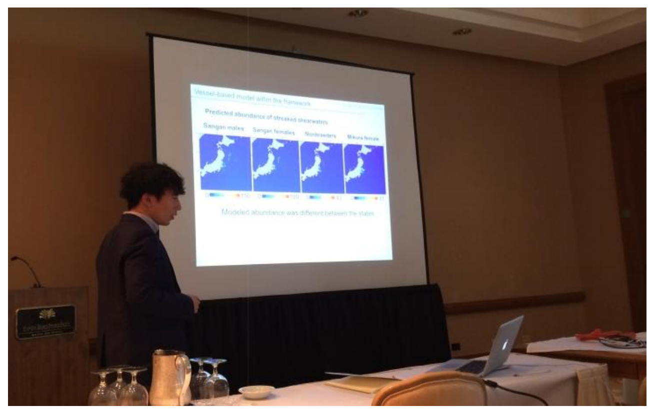
The presentation by M. Gadea Pérez-Andújar (University of Hawaii, USA) reviewed tagging results and vertical movement of deep-water sharks relative to the oxygen minimum zone (OMZ). By comparing species with different movement patterns (deep water activity within the OMZ), we may be able to understand how different species are likely to respond to more prevalent encounters with low oxygen waters. Rachael Orben (University of California Santa Cruz, USA) discussed winter movements of black-legged kittiwake from the Pribilof Islands to the sub-arctic North Pacific across three winter seasons. She found higher use of the Bering Sea during the El Niño conditions of 2009/10 and that individuals traveled farther, flew more, and used more area in La Niña conditions in 2010/11. Stable isotopes also showed greater individual variability in carbon isotopes in 2010/11, suggesting a use of a broader geographic area and/or prey base in this year.

William Sydeman (Farallon Institute for Advanced Ecosystem Research, USA) gave an invited presentation on challenges and opportunities for assessment and attribution of climate impacts on North Pacific seabirds. A meta-analysis revealed that increased temperatures had mixed effects on North Pacific seabirds, highlighting the need for more detailed examination of climate change mechanisms and responses. Additional important points were that we need more data and climate projections on mid-trophic forage species that greatly influence these top predators, and that we will likely need both mechanistic numerical models combined with statistical models to begin teasing apart the effects of climate variability from change.




*Increased variability in Cassin's auklet breeding success in recent years. From W. Sydeman's presentation.*

This invited talk was followed by two more seabird presentations from Takashi Yamamoto (University of Hokkaido, Japan) and Rob Suryan (Oregon State University, USA). Yamamoto's presentation examined both tracking data and shipboard sighting surveys of shearwaters in the Northwest Pacific. He used generalized additive models to partition sightings data into likely colony origination and sex, and also to predict changes in sea distribution with increased temperatures up to 4°C. Suryan used a 10-year time series to assess changes in common murre chick stable isotope signatures and diets as a function of local- and basin-scale environmental forcing. Specifically, he found a strong relationship between murre nitrogen isotope ratios and local upwelling intensity, suggesting possible trophic level shifts associated with upwelling regimes. It is unclear whether this represents a change in the length of the food chain or change in nitrogen values at the base of the food web. In contrast, carbon was most strongly associated with basin-scale indices of water mass transport impacting nutrient sources.



*Takashi Yamamoto discussing streaked shearwater habitat use in the Northwest Pacific.*

Chandra Goetsch (University of California Santa Cruz, USA) presented results on northern elephant seal foraging behavior changes and diet switching during the 2010 Central Pacific El Niño. Female elephant seals show extreme fidelity to their migrations, so changes in diet are likely a function of prey densities or selectivity by foraging elephant seals. Diet estimates from fatty acid analysis differed between ENSO states (negative, neutral, and positive) with positive, or El Niño, conditions being significantly different from neutral and negative (La Niña) conditions. Future analyses will examine specific remotely sensed oceanographic conditions which may be driving the behavioral and diet changes observed.

Our second invited speaker, Jeffrey Polovina (NOAA Pacific Islands Fisheries Science Center, USA), spoke about climate impacts on Hawaiian monk seals and loggerhead sea turtles relative to changes in the North Pacific Transition Zone (NPTZ). One of the strongest messages highlighted the complexity in predicting climate change effects on top predators, and why tagging studies are critical to assess impacts on these species. Specifically, models predicting a northward migration of the NPTZ may not have a large effect on sea turtles if the Kuroshio Extension and Bifurcation also migrate northward ensuring that the "highways" are still aligned with increased productivity. Furthermore, central place foragers, like monk seals, that are tied to land may no longer be able to reach critical foraging habitat after northward movement of the NPTZ, which likely will create population level effects.

Our third invited speaker, Kevin Weng (University of Hawaii, USA) gave a presentation on fish futures and how species are likely to adapt and respond to climate change. His talk discussed physiological responses to climate change and the potential interplay among $CO_2$, $O_2$ and temperature on fitness. Kevin discussed the use of end-to-end (E2E) ecosystem models such as SEAPODYM and APECOSM that are predicting climate change effects on distribution and abundance of top predatory fish. Furthermore, the point was made that we need to seek integrative funding calls to complete the research necessary to understand top predator responses to climate variability and change. Kevin also discussed the role of CLIOTOP and highlighted potential joint interests between the FUTURE and CLIOTOP programs on observing and predicting the effects of climate on top predators.

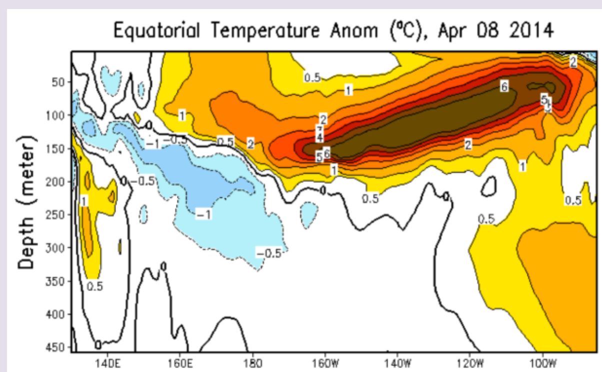
Brianna Witteveen (University Alaska Kodiak, USA) talked about the Gulf Apex Predator-Prey (GAP) integrated research project which is documenting spatial and temporal patterns in habitat use and consumption estimates of top predators in the ecosystem around Kodiak Island. These integrative surveys measured physical oceanography and lower trophic level species (zooplankton and fish) up to top predator sightings. Multi-scale data including aerial surveys, stable isotopes, and individual tracking data were also collected and can be used collectively to examine ecological changes in baleen whales since 1997.

Our final presentation was by Kathy Kuletz (U.S. Fish and Wildlife, USA) who provided an overview of available at-sea survey data for the subarctic and arctic North Pacific. A suite of studies are underway examining spatial shifts in seabird species and likely population changes such as for northern fulmars. Sightings data on seabirds are being linked to prey and oceanographic data. Long-term datasets and synthetic studies like these highlight the importance of understanding both responses to climate variability (*e.g.*, extreme climatic events) but also long-term (20+ years) trends in top predator distribution and abundance.

### *Summary and conclusions from the Workshop*

There were several key takeaway messages from the workshop discussion: 1) A need to define the term "indicator" particularly for top predators; 2) A need to identify the mechanistic processes necessary to understand and attribute climate effects to top predator ecology and demography; 3) The importance and need for the synthesis and analysis of existing data, particularly in extreme years; and 4) a need to identify life history characteristics and metrics that are inherent to sentinel species. As part of these discussions, we came up with a suite of tasks mentioned in the objectives above that we hope to accomplish as part of AP-MBM, FUTURE, and CLIOTOP upcoming activities.

**Box 1.** Climate predictions for 2014 suggest that a strong El Niño – potentially similar in magnitude to the strongest previously recorded ENSO events – is developing in the tropical Pacific that may have large ecosystem effects throughout the North Pacific. Based on discussions from our PICES FUTURE workshop, we emphasize the importance of data collection to monitor the ecosystem response to the impending El Niño. Specifically, 1) ensure existing sampling and monitoring programs on physical and biological oceanography, forage species, and top predators are continued, 2) implement additional sampling to test key mechanistic hypotheses of ecosystem change that were generated during prior ENSO events, and 3) obligate sufficient funding to compile and analyze data with respect to previous El Niño events (1982–3/1997–8). Given the broad-reaching effects of El Niño events on ocean ecosystems, data collection and analyses should be coordinated throughout PICES member countries. Understanding the response of ecosystems to extreme climate events is critical to understanding how ecosystems may respond in the future under projected climate change scenarios. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_disc_apr2014/ensodisc.html.




First, our use of the term "indicators" refers to sentinel species that reflect (indicate) the impact of climate change on upper trophic level species and may serve to highlight or even lead certain biophysical processes that particularly impact upper trophic level species. Inclusion of sentinel species in FUTURE, therefore, fulfills a critical objective of assessing ecosystem impacts of climate change. The use of sentinel species to be early "indicators" of climate change is most appropriate in situations where information obtained from them is not being collected otherwise (*e.g*., top predators can be indicators of prey species such as the abundance of Pacific sand lance, *Ammodytes hexapterus*, which is difficult to sample using traditional fisheries methods).

Second, understanding mechanisms (for example, PICES-2011 Topic Session S2, convened by Alheit, Hazen, Katugin, Suryan, Watanuki, Yasuda, 2011; Marine Ecology Progress Series Theme Section 487: 176–304, 2013) of how sentinel species are affected by climate change is critical to modeling ecosystem impacts to upper trophic levels. This effort will require a combination of statistical, numerical, and energy flow modeling approaches to identify mechanisms. The group also acknowledged that understanding all mechanisms is unrealistic given the suite of variables integrated by top predators, but identifying a few dominant mechanisms is realistic and should be a goal in the future. Particular life history traits may cause various top predators to respond differently to climate change such as a) central place forager *vs*. migratory species, b) trophic position in the food web, c) specialist *vs*. generalist foragers, d) air breather *vs*. gilled organism. Consideration of these traits have important implications when testing response mechanisms. We proposed that a subset of the workshop participants develop a review paper that examines the framework needed and mechanisms involved to understand responses of top predators to climate change.

Third, there is still much to be learned by compiling and analyzing existing datasets, particularly in response to extreme climatic events. This is critical for learning from past events, but also for targeting future research to fill knowledge gaps. It is essential to request adequate funds for data synthesis in future funding of field data collection.

Fourth, and perhaps most importantly, there was much discussion about understanding climate variability, particularly extreme years and the top predator response to these events. There is a suite of potential responses (*e.g*., spatial shifts, temporal shifts, dietary changes, fitness and demographic change). Furthermore, with a potentially extreme El Niño event developing in the second half of 2014 (see Box 1), there is an urgent need to understand ecosystem responses to this event. We have written a statement for distribution among the PICES community stating the importance of continued measurements and, where possible, additional data collection. We foresee the need to collaborate across PICES committees to identify physical, biological, top predator, and ecosystem data needs to measure the response of the North Pacific to climatic extremes.

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