PROPOSAL for a PICES

Working Group on *Climate and Ecosystem Predictability*

Revisions completed on March 15, 2017

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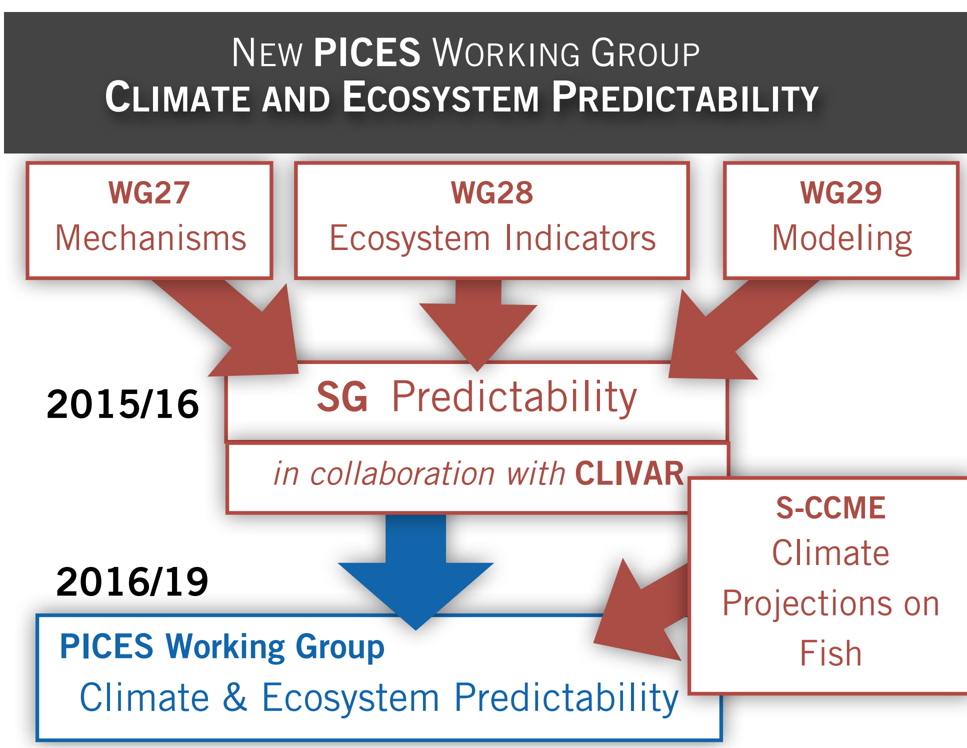
Background

The PICES Working Groups 27, 28, and 29 on North Pacific Climate, Regional Modeling and Ecosystem Indicators ended in 2015. While WG27 has identified and described a series of climate and ecosystem mechanisms that have forecast potentials ranging from 3 months to 10 years, WG29 has developed a set of modeling strategies to simulate these mechanisms at both the basin and regional-scale over the North Pacific. Complementary to WG27 and WG29, the outcomes of WG28 provide us with a series of key ecosystem indicators that can be connected to climate processes identified by WG27 and modeled by WG29. Furthermore, the activities of WG27 and WG29 strongly leveraged collaborations with CLIVAR by conducting joint sessions and by entraining CLIVAR expertize. Building on the outcomes of WGs 27, 28, and 29, and the CLIVAR collaborations, we propose a new PICES Working Group on Climate and Ecosystem Predictability (**WG-CEP**) that will interact with CLIVAR towards integrating the knowledge gained on the mechanisms of Pacific climate, regional modeling, and ecosystem indicators to identify and quantify the sources of climate and ecosystem predictability in the North Pacific.



Motivation and Goals

To identify, diagnose and quantify predictable response in North Pacific marine ecosystems that arise from regional- and large-scale climate processes

The North Pacific marine ecosystems are primary sources of ecosystem services for Russia, Canada, Japan, China, Korea and the US (e.g. fishing, shipping, and recreation). Long-term historical observations of physical and biological variables been collected around the North Pacific rim since the 1950s, leading to an excellent foundation for understanding the ecosystem impacts of dominant climate processes such as the Pacific Decadal Oscillation, North Pacific Gyre Oscillation, and the El Niño-Southern Oscillation (ENSO). In the North Pacific, regional- and large-scale climate forcing impacts a wide range of physical and biotic processes including temperature, stratification, winds, upwelling, and primary and secondary production. Moreover, there is some predictability in the physical system on seasonal (Stock et al. 2015) and even longer (e.g., Qiu et al. 2014) times scales. Nevertheless, there has been no systematic and synergistic attempt to use this knowledge to forecast marine ecosystem responses to climate forcing, which is a primary goal of the PICES FUTURE science plan and CLIVAR. The new PICES working group will leverage the international expertise within PICES and foster more active interactions with CLIVAR to "*identify, diagnose and quantify predictable response in North Pacific marine ecosystems that arise from regional- and large-scale climate processes.*"

Terms of Reference (TOR)

Below we articulate the WG-CEP goals in a set of terms of reference, which are also summarized schematically in diagram 1. Along with each TOR, we also indicate which suggested members bring the relevant expertise.

1. **Identify a set of North Pacific ecological indicators and/or marine ecosystem functional responses of fish and shellfish, which show predictable responses to large- and regional-scale climate forcing (Jacox, Rykaczewski, Siedlecki).**

The WG will (1) identify a finite number of ecological indicators and/or marine ecosystem functional responses that are prime for making ecosystem predictions, and (2) diagnose the regional mechanism and drivers controlling these ecosystem responses (see diagram 1). The selected mechanisms can act on any of the following timescales: intra-seasonal, seasonal, interannual, decadal and climate change. To identify this set of mechanisms, the WG will (a) use findings from WG28 on the ecosystem indicators and WG27/29 on regional climate mechanisms, and (b) coordinate with the ongoing section S-CCME, to align some of the prediction efforts to complement the gaps in S-CCME.

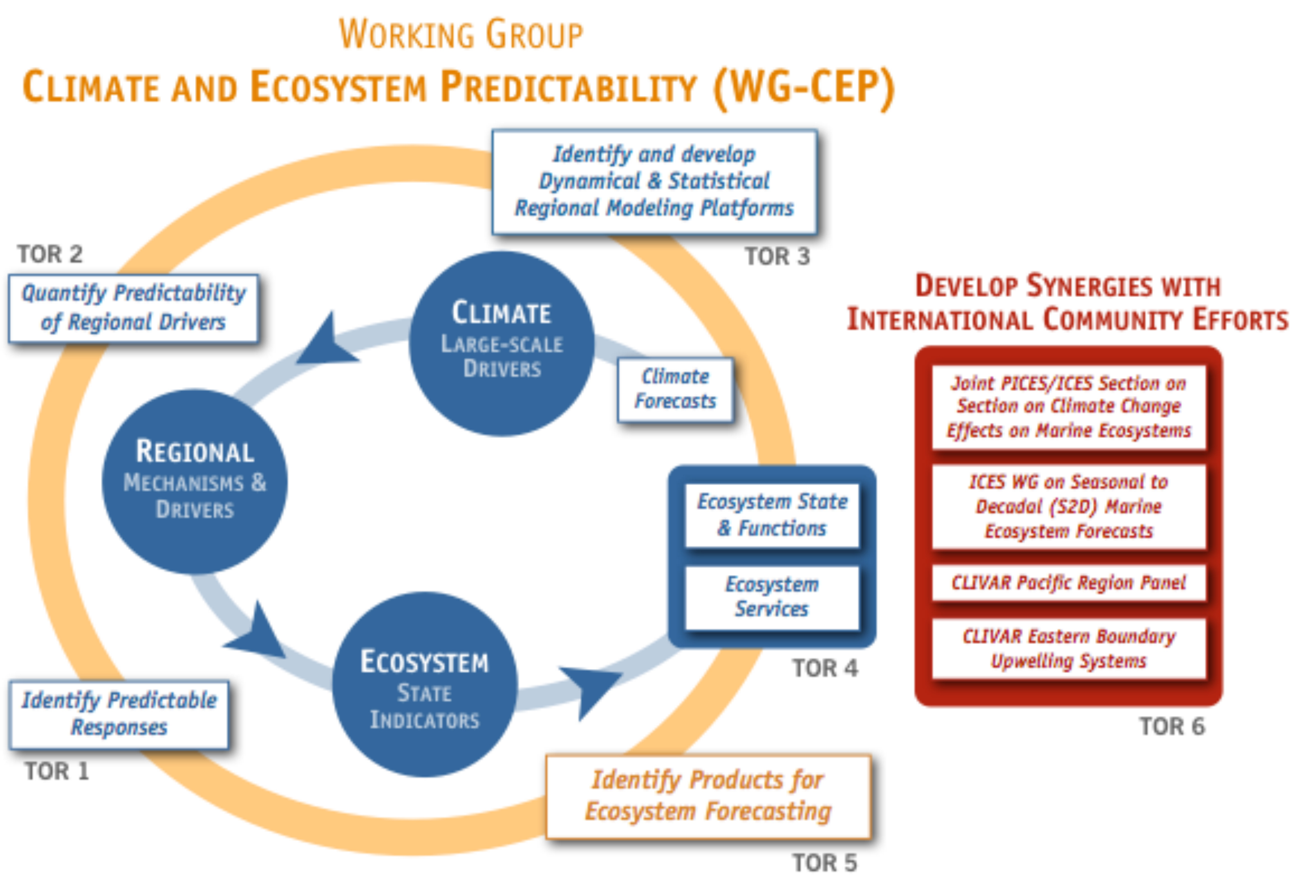


Diagram 1: Schematic of WG-CEP Terms of Reference (TORs).

2. Quantify the predictability of the regional ecosystem drivers that are controlled by large-scale climate variability and change (Di Lorenzo, Jacox, Minobe, Nonaka, Capotondi).

The WG will diagnose the large-scale climate processes that relate to the regional physical-biological mechanisms associated with predictable ecosystem responses (e.g. the ones identified in TOR 1). The WG will also quantify the predictability and uncertainties from large-scale climate forcing to regional ecosystem drivers to ecosystem responses (e.g. blue path in diagram 1). To accomplish this TOR the WG will make use of output of IPCC-class climate models as well as regional ocean model simulations and reanalyses. This effort will require examination of a great amount of data from a number of model simulations of extended durations. The WG will collaborate with representatives from CLIVAR to devise feasible strategies for data analysis and archival.

3. **Identify dynamical and statistical modeling frameworks for climate and ecosystem predictability (Chai, Jacox, Capotondi, Nonaka).**

   The WG will identify a set of modeling frameworks and existing model outputs (e.g. IPCC-class climate models) that can be used to evaluate the predictability dynamics identified in TOR 1 and 2. To do so, the WG will leverage outcomes and products from WG29.

4. **Identify how and which ecosystem predictions can be integrated in the management of ecosystem services (Chiba, Kulik, Rykaczewski, Siedlecki, Capotondi).**

   The WG will engage with the section on human dimensions and other stakeholders to identify what type of ecosystem prediction can be (1) potentially integrated in managing ecosystem services and (2) used to characterize the ecosystem state and function in selected regions of the North Pacific. This effort will also consider the issues that arise in operational maintenance of prediction systems.

   For this particular TOR (#4), we note that we seek additional expertise. Currently, suggested members of the group have expertise in physical processes and the biology of lower-trophic-level populations, however, incorporating climate information into the management of exploited stocks is one area that few individuals have experience.

5. **Identify climate and ocean products that can be used to begin making predictions of North Pacific marine ecosystems (Jacox, Siedlecki, Capotondi).**
   The WG will identify sets of variables that are presently available, or expected to be available soon, for experimental predictions. Initially, there may be a focus on regions and predictands for ecosystem predictions on timescales of months to a year. The WG would collaborate with CLIVAR towards making the data available for prediction experiments.

6. **Outcomes and synergies with international efforts (Rykaczewski, Capotondi, Nonaka).**
   The WG will engage in synergistic activates with other efforts and group that work on climate and ecosystem predictability. These include the ICES WG on Seasonal to Decadal (**ICES-S2D**) Marine Ecosystem Forecasts, Joint PICES/ICES Section on Section on Climate Change Effects on Marine Ecosystems (**S-CCME**), the CLIVAR Pacific Region Panel, and the CLIVAR Eastern Boundary Upwelling Systems Research Focus. Specifically, WG will plan joint theme sessions and workshops at the ICES and PICES annual meeting and a session at the 4th International Symposium on Effects of Climate Change on the World's Ocean. The WG will also co-sponsor workshops and symposia with CLIVAR.

Examples of Climate and Ecosystem Predictability Dynamics

There are several dynamics of climate and ecosystem predictability acting on seasonal, interannual and decadal timescales that have been identified by previous research within PICES and CLIVAR expert groups. See for example the report of the joint GLOBEC/PICES/ICES workshop on Forecasting Ecosystem indicators with Process Based Models http://wg27.pices.int/ecofor/ contributed by PICES WG27. Below we provide some key examples for different timescales of predictability.

1. Seasonal forecasts of oceanic temperature

Source of physical predictability: There are two main sources of predictability on timescales of months to roughly a year. First, there is persistence, which due to the slow decay of pre-existing anomalies, can provide meaningful indications of the future state of the ocean. The memory in the system can be enhanced in situations when ocean conditions at depth, which tend to be relatively insensitive to air-sea interactions, re-emerge into the euphotic zone due to effects such as upwelling and vertical mixing. Second, there is predictability in the atmospheric forcing of the ocean in some regions and phases of the large-scale climate system. The most widely appreciated example here is ENSO, which is typically accompanied by large-scale perturbations in the atmospheric circulation that provide much of the existing skill in seasonal weather prediction. This source of skill can also be exploited for oceanographic forecasts in selected regions including the northeast Pacific (Jacox et al. 2016a). It should be noted that ENSO is not the only potential source of prediction skill on timescales of seasons, as discussed by Stock et al. (2015) for regions such as the Hawaiian Islands and the Bering Sea

Ecosystem impact: There are a variety of documented impacts of oceanic temperature change on marine species. Examples of these include regulation of metabolic rate, shaping of biogeographic boundaries for species, emergence of harmful algal blooms.

Examples

The decay phase of strong El Niños that develop in the tropics during the summer and fall has predictable ecosystem impacts along the eastern boundary of the North Pacific (e.g., Jacox et al., 2016b). This predictability is associated with relatively robust tropical to extra-tropical teleconnections (Fig. 1), which impact key ecosystem drivers such as changes in ocean temperature, transport and upwelling. Observed temperatures in this region are being used as predictors by NOAA's Northwest Fishery Science Center in forecasts of adult returns of coho and Chinook salmon (Burke et al. 2013); predictions of these temperatures with useful skill may be feasible. For this region, SST forecasts may be suitable for forecasting sardine habitat suitability (Kaplan et al. 2016) and informing sardine catch limits (Tommasi et al. 2016).

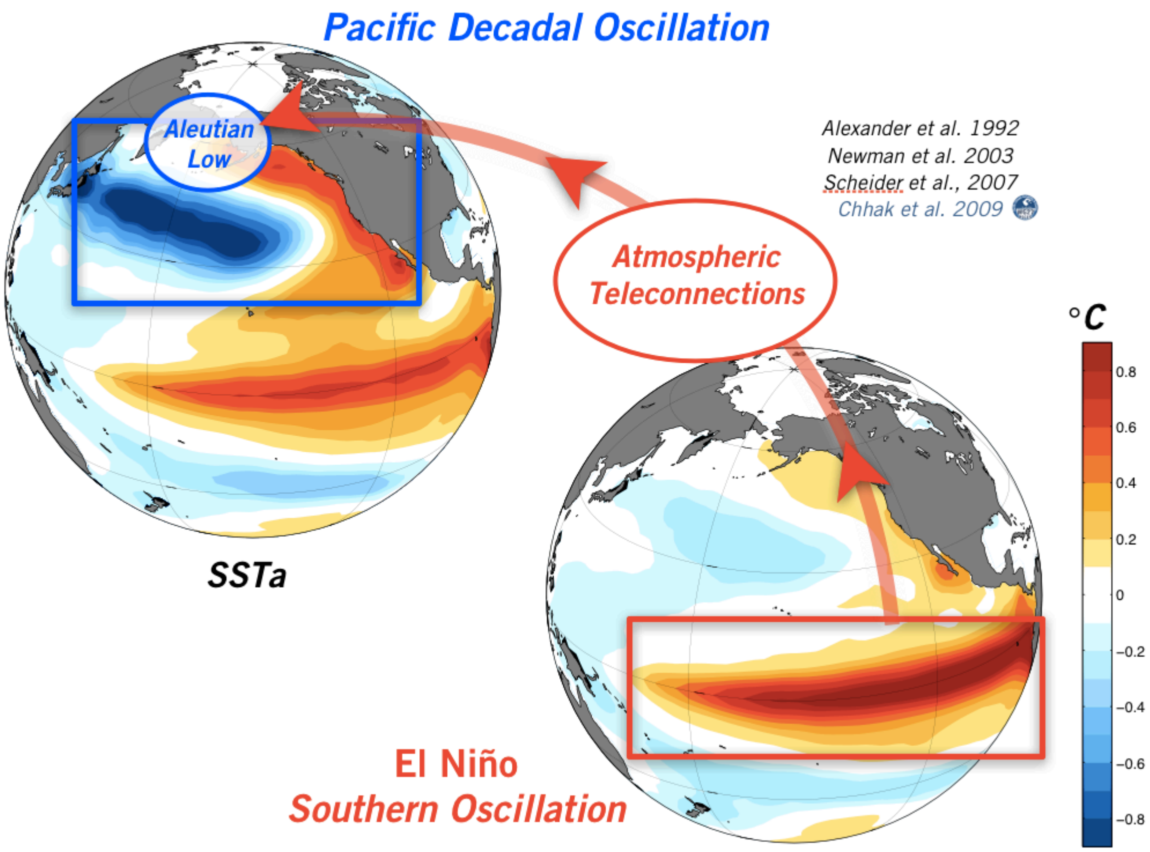


Figure 1. SSTa associated with El Niño and its teleconnection to the North Pacific. El Niño anomalies in the tropics during the fall lead to predictable SSTa anomalies in the following winter and spring in the North Pacific.

2. Interannual predictions in the Kuroshio-Oyashio Extension (KOE)

Source of physical predictability: The propagation of large-scale oceanic Rossby waves from the central North Pacific into the western boundary influences dynamics of the KOE. It has been recognized that atmospheric variability in the central and eastern North Pacific excite long Rossby waves that arrive into the KOE 3-5 years later. When these waves arrive they drive predictable responses in the transport of the KOE, oceanic temperatures and the eddy field.

Ecosystem impact: Changes in KOE oceanic transport and temperatures can modify the species assemblage in the KOE (e.g. zooplankton), the statistics of ecosystem hotspots, and the reproductive success of higher trophic levels ultimately impacting the bottom-up energy flow through oceanic food web.

Examples

Linkages exist between Japanese sardines and gyre circulation. Reproductive success expressed by log-normalized residuals recruitment (LNRR) for the Pacific stock of Japanese sardine has historically been linked to changes in surface temperature. It has also been noted that LNRR are more strongly correlated (R=0.63) with subsurface temperature (0-400m) in the Kuroshio extension southern area (KESA) and in the western subtropical gyre (Fig. 2). Changes in subsurface temperature in this region are connected to changes in basin scale wind stresses and the westward propagation of Rossby waves from the North Pacific interior into the KESA region. A correlation analysis between the sardine time series (LNRR) and large-scale wind stresses shows a maximum correlation (~0.3) in the central North Pacific when the winds lead the sardines by 3-7 years (Fig. 2). This suggests that large-scale changes in the winds excite Rossby waves in the central North Pacific, which then propagate the signal into the Kuroshio with a time lag. This time lag may lead to useful prediction of the interannual variability of the sardine population.

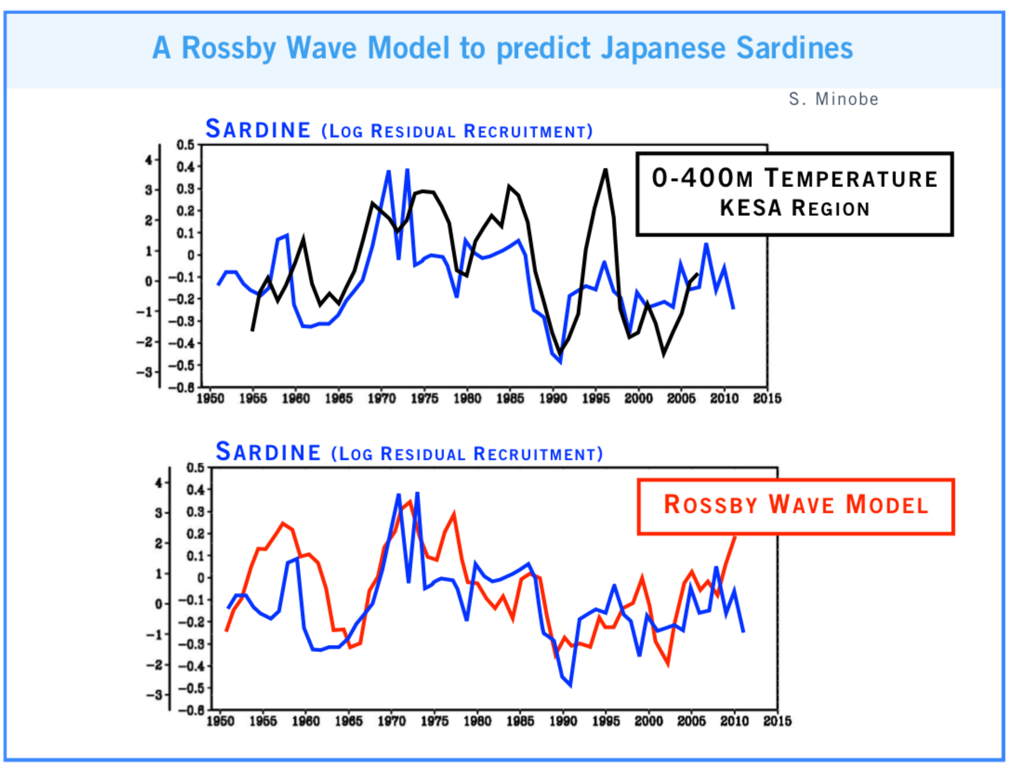


Figure 2. Correlation between upper ocean temperatures and sardines in the KOE. Upper ocean temperature are strongly influences by sea level height anomalies that propagate from the central North Pacific to the KOE. This propagation takes about 2-3 years and can be potentially exploited for climate and ecosystem predictions in the KOE. Analysis performed by Shoshiro Minobe.

In this example we diagnose the adjustment of the gyre scale circulation to the wind forcing using a simple Rossby wave model for the North Pacific forced by the NCEP wind stresses. The reconstructed sea surface height anomalies of the model compare well with the satellite and show a region of very strong correlation with the sardines in the KESA region. We then develop and index of the model sea surface height in the KESA region and compare it to the sardine timeseries (Fig. 2). The resulting high correlations (R=0.65) shows that this simple model has high skill and may be useful for future predictions of sardines given that the sea surface height anomalies associated with the waves arrival in the Kuroshio are a time-lagged (3-7 years) response to wind forcing in the interior of the gyre.

Future studies will explore this model in more depth and understand the potential mechanisms linking the changes in the gyre scale circulation with the sardine life cycles.

3. Decadal predictability of nutrients and oxygen in upwelling systems of the Northeast Pacific

Source of physical predictability: The subsurface advection of water masses with specific physical and biological anomalies takes about 10 years to propagate from the sub-tropical gyre interior towards the upwelling region of the Gulf of Alaska and California Current System. When these anomalies are entrained into the upwelling systems and come up to the surface they can trigger responses in the physical and biological system.

Ecosystem impact: Changes in the nutrient and oxygen content of the upwelling source water can have impact on primary production and on the statistics of coastal hypoxia. Both of these processes impact the marine food web.

Examples

In coupled earth-system models, interannual to decadal scale variability in the depth of wintertime convection in the western North Pacific stimulates anomalies in the vertical distribution of nitrate, oxygen, and carbon dioxide. These anomalies propagate from west to east with the North Pacific Current with transit times on decadal scales. As a result, anomalies in the deep-water biogeochemical properties of the eastern North Pacific may be predicted several years in advance given knowledge of convection in the western North Pacific. This linkage is one mechanism which may contribute to harmonization of decadal, ecological variability across the Pacific with a delayed response of the California Current relative to changes in the Kuroshio-Oyashio extension region.

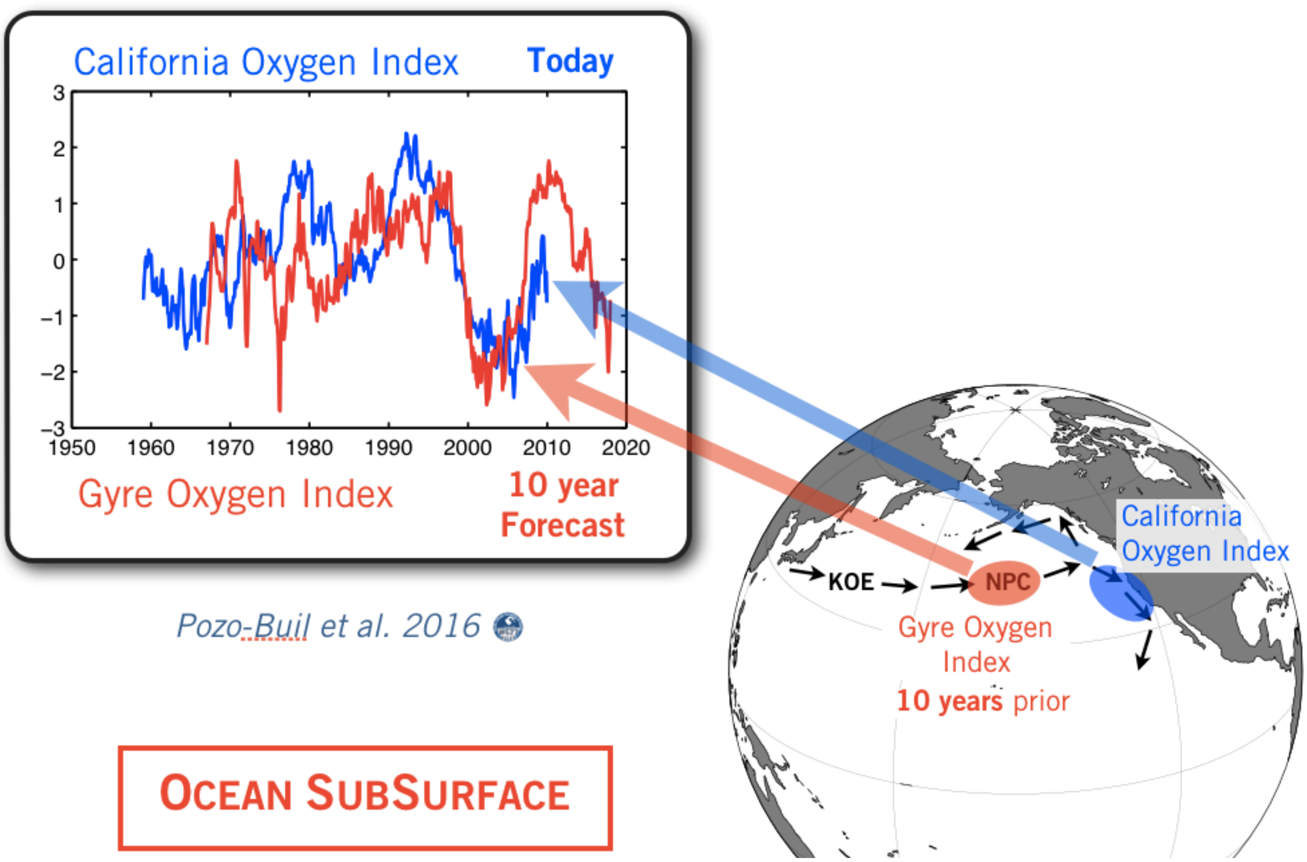


Figure 3. Forecasting subsurface oxygen in the California Current by tracking anomalies coming from the North Pacific Gyre. Ocean tracer anomalies in the core of the North Pacific Current take up to a decade to appear along the eastern boundary current system. These anomalies have the potential to alter the properties of upwelling

water masses in terms of oxygen, carbon, and nutrient content, which in turn have implications for local ecosystems (e.g. hypoxia, productivity, ocean acidification, etc.). Another example of exploiting sub-surface dynamics is the recent study by Pozo-Buil et al. (2016a,b), showing how the observed subsurface oxygen content in the California Current System can be potentially predicted by monitoring anomalies of ocean tracers upstream of the North Pacific Current (Fig. 3). The low-frequency modulation of oxygen anomalies in the region of the upwelling source water may become a useful indicator of the statistics of coastal hypoxia.

Joint US CLIVAR/NOAA/PICES/ICES/OCB Workshop

Among the activities of the Study Group on Climate and Ecosystem Predictability (SG-CEP) that led to this proposal, SG-CEP members co-organized (E. Di Lorenzo, PICES FUTURE SSC) and contributed (N. Bond, SG-CEP Chair, A. Capotondi, CLIVAR Pacific Panel; Ryan Rykaczewski, CLIVAR Upwelling Research Focus) to an international Joint US CLIVAR/NOAA/PICES/ICES/OCB Workshop on Forecasting ENSO impacts on marine ecosystems of the US West Coast organized by Emanuele Di Lorenzo and Arthur Miller. During the workshop, the participants engaged in identifying a set of ecosystem indicators that were sensitive to El Niño and potentially predictable. Following the path outlined in the terms of reference for WG-CEP (see diagram 1), the group identified the regional physical/biological mechanisms that act as ecosystem drivers and their relationship to large-scale climate forcing, in this case El Niño. Below in table 1 is a summary of these efforts. The workshop described above considered the NE Pacific Ocean along the US west coast. Similar endeavors are warranted for other regions such as the western North Pacific, for which there is less complete understanding, but emerging indications of climate-ecosystem linkages that might be exploited. We anticipate that activities such as these are the foundation for developing the proper mechanistic framework needed to explore the predictability using statistical and dynamical models. More details can be found in the official workshop report (Di Lorenzo et al. 2016).

Rank	Ecosystem Indicator	Region and Season	Type of sensitivity	Regional Physical-Biological Ocean Process	Forcing function	Change during El Niño
1	Habitat availability	Entire CCS, but also specific to a region	Instantaneous and cumulative	Wind-driven upwelling and transport	Winds	Warm habitat, high salinity, low productivity
4	*Pseudo-nitzschia* spp/Domoic Acid	NCCS & CCCS, spring-summer	Delayed 3 month lag	Physiological response to change in temperature and nutricline depth, changing biogeochemistry of source waters	Surface heat fluxes, alongshore winds, curl, CTW (in SCCS)	Blooms during El Niño, but unclear if this relation is strong, temperature is not the only control.
	Primary production	Entire CCS, winter-spring-summer	Variable lag depending, instantaneous, delayed	Nutrient fluxes, upwelling strength, nutricline depth, and source waters, retention	Alongshore winds, curl, CTW, phenology & timing of spring transition in winds	Lower productivity
4	Copepod assemblage (cold northern vs warm southern species)	CCCS & NCCS, spring-summer	Nearly instantaneous, some degree of integration	MLD, low upwelling, transport, Advection of populations and habitat, both along shelf and cross shelf	Winds/Aleutian low, CTW, strong Ekman	Warm species appear

3	Zooplankton community structure (biogeographic affinity)	SCCS, winter-spring	Nearly instantaneous	Advection of populations and habitat, both along shelf and cross shelf	Winds/Aleutian low, CTW with strong mesoscale eddy influence	Warm species appear
	Krill (Thysanoessa spinifera) abundance	Entire CCS, spring	Delayed and cumulative	Suppressed thermocline, low nutrient -> chl, predation, alongshore advection	CTWs (both time-scales), large scale alongshore advection changes, upwelling winds, surface heat flux	Decrease
	Krill (Nyctiphanes simplex) abundance	SCCS, spring	Instantaneous			Increase
1	Red Crabs	SCCS & CCCS, winter-spring-summer	Instantaneous (TBD)	Transport anomalies, (physiological response to warmer water?)	Along-shore winds and pressure gradient, CTW	Increase
3	Market squid	CCCS and SCCS	Instantaneous for distribution and delayed for recruitment	Temperature/thermocline depth - reduces spawning habitat	Surface heat flux, wind stress curl, CTW	Collapse
1	Sardine biomass	Entire CCS	Instantaneous for spawning and distribution, recruit are delayed, biomass is	Warm temperatures, smaller zooplankton positive effect	Reduced upwelling winds, broad scale heating	Changes in distribution

			integrated			
1	Anchovy	Entire CCS	Instantaneous for spawning and distribution, recruit are delayed, biomass is integrated	Diatom biomass (larger cell) --> volume of upwelled water		Changes in distribution
1	Survival Salmon (juveniles)	NCCS & CCCS, spring-summer	Cumulative	River flow, food supply in ocean	Atmospheric change in precipitation (now pack), phenology, (+ as with zooplankton)	Decreases in Pacific Northwest, not obvious in CA
1	Adult sockeye return (to Fraser River)	NCCS, summer	Cumulative	Temperature at sea at time of returning / Ekman controls on temperature	Aleutian low	Path of the return changes to Canada
1	Warm assemblage of mesopelagic fishes	SCCS, spawning season, spring	Delayed 0-3 months	Warm water advection from south/central gyre - larval transport	Surface to subsurface flow (CUC resolved well in models?)	More abundant
2	Common Murre (reproductive success)	CCCS (Winter-Spring)	Delayed, integrated	Food (fish) availability, thermocline depth, altered upwelling (?)	Kelvin waves, surface heat fluxes, timing of upwelling winds	Decrease reproductive success
3	Top predator reproduction and	Entire CCS	Cumulative	Advection of prey, temperature, upwelling, ecosystem production,	Timing and intensity of winds.	Species dependent

	abundance			mesoscale structure	Coastally trapped waves	
	Top predator distribution	Entire CCS	Instantaneous and delayed	Advection of prey, temperature, upwelling, ecosystem production, mesoscale structure	Timing and intensity of winds. Coastally trapped waves	Changes in distribution

Table 1. ENSO-related Ecosystem Drivers in the California Current System (source Di Lorenzo et al. 2017)

Membership

PICES Co-Chairs: Michael Jacox & Masami Nonaka

In order to leverage the existing knowledge and products generated by the ending WGs 27, 28 and 29, the past co-chairs of these working groups have participated as members of the SG-CEP in order to develop the terms of reference and identify effective co-chair for the PICES WG-CEP. Two co-chairs have been identified with diverse expertize who have both worked on predictability dynamics of regional & large-scale climate and ecosystems. Based on recent discussions, it appears that International CLIVAR and US CLIVAR may each be able to support the participation of a scientist on this proposed PICES WG.

Michael Jacox (USA): Physical-biological oceanographer at the USA NOAA Southwest Fisheries Science Center. Primary research focus is on physical-biological interactions in the ocean and their connections to climate, particularly in the northeast Pacific. He studies interannual to decadal scale variability in the regional physical ocean environment, particularly the US West Coast, its relationship to known modes of climate variability (e.g. ENSO) and long-term climate change, potential impacts of this variability on phytoplankton and higher trophic levels, and sources of predictability. His research efforts rely on numerical ocean models, and also leverage observational data from satellites, ships, and autonomous ocean platforms, depending on the problem at hand.

Masami Nonaka (Japan): Senior Scientist and Deputy Group Leader of the *Climate Variability Prediction and Application Research Group* in the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). His research is primarily focused on the regional and large-scale predictability associated with large-scale climate dynamics. He is an expert in ocean dynamics and numerical modeling with particular focus on the western North Pacific.

CLIVAR Co-Chairs: Ryan Rykaczewski & Antonietta Capotondi

During the activities of the SG-CEP several members of the CLIVAR international community served as members to shape the terms of reference and identify co-chairs for the joint PICES/CLIVAR WG-CEP. In order to entrain a broad expertise from several of the ongoing research efforts in CLIVAR, we have identified two CLIVAR co-chairs for the group that connect the WG-CEP activities to the new Upwelling Research Focus and the Pacific Panel. The CLIVAR co-chair will act as the point of contacts between the working group activities and CLIVAR.

Ryan Rykaczewski (Upwelling Research Focus): Biological and fisheries oceanographer and assistant professor at the University of South Carolina/USA who studies the responses of ecosystem and fisheries production to past and future climate variability and climate change. He investigates the biogeochemical implications of changes in physical climate that are particularly robust in the projections of atmosphere-ocean general circulation models (e.g., meridional shifts in zonal winds, increases in ocean stratification, and changes in phenology).

Antonietta Capotondi (Pacific Panel): Physical Oceanographer at NOAA/USA who studies the influence of large-scale ocean circulation in climate variability and change using observations, climate models, as well as Linear Inverse Models (LIMs). A major topic of interest is El Nino Southern Oscillation (ENSO), with emphasis on its dynamics, diversity, decadal modulation, precursors, and impacts.

Suggested PICES Members and CLIVAR Participants

PICES

Michael Jacox (USA)
Sam Siedlecki (USA)
Emanuele Di Lorenzo (USA)
Masami Nonaka (Japan)
Akinori Takasuka (Japan)
Sanae Chiba (Japan)
Fei Chai (China)
Vladmir Kulik (Russia)

CLIVAR

Ryan Rykaczewski (Upwelling Focus)
Antonietta Capotondi (Pacific Panel)
Shoshiro Minobe (co-chair CDP Panel)

Ken Takahashi (Pacific Panel)

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