Alternative Proposal for Climate FY10-14 Planning and Programming

Title of Activity: Climate Variability and Change in the California Current Ecosystem: A Plan for Research to Inform Management

Principal Investigators: J. Barth[a], H. Batchelder[a], D. Checkley[b] , R. Davis[b], P. MacCready[c], J. McWilliams[d], W. Peterson[e], T. Strub[a]

[a] College of Oceanic and Atmospheric Sciences, Oregon State University
[b] Scripps Institution of Oceanography, University of California, San Diego
[c] School of Oceanography, University of Washington
[d] Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles
[e] Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA

Contacts: Dave Checkley (dcheckley@ucsd.edu, 858 534-4228) and Jack Barth (barth@coas.oregonstate.edu, 541 737-1607)

Program and Capability: Climate and Ecosystem Goal Teams

Background

Introduction

The California Current Ecosystem (CCE) contains a diverse assemblage of environments, communities and species of great societal value for reasons ranging from fisheries and recreation to navigation and security. The CCE supports extensive commercial and recreational fisheries that target pelagic and demersal finfish and invertebrates, including anchovy, hake, halibut, rockfish, salmon, sardine, squids, shrimp and Dungeness crab. Physical forcing of the ecosystem varies on time scales of days to decades, including event-scale changes in winds, seasonal cycles, and longer scales associated with ENSO[1] and warming-cooling cycles associated with the PDO[2]. Many fisheries respond strongly to physical forcing. Sardine and anchovy populations have varied for millennia on the scale of ~60y, often out of phase with one another. Coho salmon survival rates vary over an order of magnitude, and largely in concert with the PDO. Market squid landings are closely associated with El Niño, plummeting during all moderate-to-large events. Fished and unfished populations are important within the ecosystem as predators and prey, affecting taxa ranging from phytoplankton, copepods, euphausiids and forage fish to marine mammals and seabirds. Moreover, organisms of the CCE affect global biogeochemical cycles. Harmful algal blooms and hypoxia are becoming more frequent and widespread.

Variability in physical forcing and ecosystem response has been particularly strong over the past decade. The largest El Niño of the past century, in 1997-1998, was followed by a shift in ecosystem structure to a high productivity state, associated with a shift in the PDO to a cool phase in 1999. This phase ended on a high note in 2002 with an anomalous intrusion of nutrient-rich, sub-arctic water into the CCE. Managers and scientists were encouraged by these events, believing that the CCE might have shifted to a cool, productive regime that might last for decades. However, further change occurred in 2002, to unproductive "El Niño-like" conditions.

[1] El Niño – Southern Oscillation (http://www.cdc.noaa.gov/ENSO/)
[2] Pacific Decadal Oscillation (http://jisao.washington.edu/pdo/)

The result was failed recruitment of rockfish and many seabirds in 2005, and some of the lowest returns of salmon to Pacific Northwest rivers since the mid-1990s. Extreme hypoxia occurred, with fish kills common off the Washington and Oregon coasts. And now, in keeping with the recent, extreme variability, the CCE appears to have changed yet again, entering another cool and productive phase, with a La Niña developing.

Given the extreme and unprecedented level of climate variability and ecosystem response, can we hope to achieve the ability to predict fisheries yields? Can we help the managers of water usage on the Columbia, Klamath or Sacramento Rivers, concerned with hydropower and irrigation, make decisions relative to the water needs of salmon? Can we predict the effects of climate change on the CCE, including exploited species? These are challenges for scientists who need to inform managers, for we presently have poorly resolved and coordinated observing systems and lack operational physical and ecosystem models. Most important and fundamentally, we lack an understanding of the mechanisms by which climate affects the ecosystem. Lacking a mechanistic understanding, we are unable to predict the future state of the CCE and its populations, particularly the higher trophic levels, to adequately inform managers. There is a clear need for scientists to develop predictive models. We argue here that there are now in place the observations, observing systems, and models necessary for us to propose a long-term plan of research on the climate and ecosystem of the California Current region. Our objective is to develop the means, with improved observation, process studies, modeling, and data use, to better inform management and policy.

Our goal is to establish a new research program on climate and ecosystems, as was done for weather forecasting in the 1960s and 1970s, that will lead to our ability to skillfully forecast the physical state of the California Current and the biological status of selected species so as to inform decision makers. The CCE is an ideal test bed for this work because the climate signals and ecosystem variations are large and clear, and an extensive patchwork of program elements exists. The time is right to embark upon such an experiment due to the presence of existing and incipient observations and research programs, new and emerging technologies and high-resolution computer models. Thus, we propose here a coordinated program of observation and modeling to achieve a better understanding and ability to predict and forecast.

Our program addresses many of the external drivers and changes in NOAA corporate priorities, including (a) a focus on climate change impacts on ecosystems, (b) development of regional approaches to ecological monitoring and forecasting, and (c) preparation of integrated ecosystem assessments. Each of these activities will contribute to NOAA's new Ecosystem Approach to Management. To initiate this new program, we convened a workshop, "Climate Effects on California Current Ecosystems," November 14-16, 2006 in La Jolla, co-sponsored by PaCOOS[3], JIMO[4] and CIOSS[5], and attended by over 60 scientists and managers from both government and academia. A CCE-based program of observation and modeling to better inform management and policy was enthusiastically endorsed. The need to inform decision makers in the face of unprecedented climate change could not be greater.

---

[3] Pacific Coast Ocean Observing System (http://www.pacoos.org)
[4] Joint Institute for Marine Observations (http://www.jimo.ucsd.edu)
[5] Cooperative Institute for Oceanographic Satellite Studies (http://cioss.coas.oregonstate.edu/)

Climate Change and the CCE

Global and regional climate-ocean models indicate that the warming climate will bring new changes, possibly including increased stratification of the ocean and frequency and intensity of extreme events such as storms, El Niños, and droughts, with profound effects on the CCE. Ecosystem impacts may be severe, particularly if the frequency of El Niño increases and/or the pattern of the PDO favors an increased number of years with warm ocean conditions. The combined effects of long-term change in stratification and winds will have important effects on coastal and open-ocean upwelling, key processes of enrichment in the CCE. Another important impact on western states is that precipitation in winter is predicted to change to less snow and more rain, thus less snowpack, altering the hydrology of coastal river systems and necessitating an increase in the capacity to store water in reservoirs of large river systems. In general, changes in precipitation may have large impacts on salmonids and other anadromous and estuarine-dependent organisms, such as herring and halibut, as well as on coastal water quality in general. Altered circulation and production will affect the occurrence and extent of hypoxia, with profound effects on demersal and benthic habitats and organisms. Latitudinal shifts in the distribution of populations and the timing (phenology) of processes critical to them, including seasonal cycles of production, are particularly sensitive to climate change.

Existing Capabilities

A patchwork of observing activities exists for the CCE. Weather has been observed along the entire coast for decades, resulting in long climate records. Oceanographic observations of a wide spectrum exist from ships, buoys, and other platforms in the CCE for a similar time span. Ocean temperature, height, winds, and color have been observed from NOAA weather buoys and satellites, in some cases for more than three decades. New technologies, including Doppler radars, autonomous vehicles, and underwater observatories continue to evolve and be implemented. Many of these have been developed and used first on the US West Coast.

Biological observing has also occurred over many decades and locations in the CCE but without coordination. The preeminent program is CalCOFI[6], now in its 58th year and augmented by the CCE LTER[7] program. CalCOFI and CCE LTER focus on hydrography and lower trophic levels, but also ichthyoplankton, marine mammals, and seabirds. An analogous program, IMECOCAL[8], exists in the CCE off Baja California. Similar, long-standing sampling programs exist in Monterey Bay, off Newport, Oregon, and southern British Columbia. NOAA NMFS has carried out both regional and coast-wide acoustic, trawl, and visual surveys to assess taxa including sardine, hake, rockfish, and marine mammals since 1977.

Significant progress has been made in modeling the physics of the CCE, including important influences of mesoscale circulation on lower trophic levels. Advances are occurring in the use of atmosphere-ocean global climate models (AOGCMs) to model global climate variability,

---

[6] California Cooperative Oceanic Fisheries Investigations (http://calcofi.org)
[7] California Current Ecosystem Long-Term Ecological Research (http://cce.lternet.edu/)
[8] Investigaciones Mexicanas de la Corriente de California (http://imecocal.cicese.mx/)

including human-induced changes. Progress is also being made on regional models of air and sea physics and lower trophic levels, e.g. phytoplankton and microzooplankton. The use of regional models nested within AOGCMs, for the first time, enables modeling and predicting ecosystem states under future climates. Regional predictions are central to our program.

Models based on statistical characteristics of the past behavior of a system have formed the basis of much of fisheries management to date and will remain important in the future. ECOPATH and ECOSIM[9] have been applied to the CCE but these models lack physical forcing and thus have limited value for predicting impacts of climate change on marine ecosystems. Needed are deterministic and probabilistic models of the ecosystem and its components, including populations of both exploited and non-exploited species. While dynamical models of the physical state of the CCS have been developed, few models exist for higher trophic levels, let alone specific fish stocks, the basic unit of management. The need for rational, computable models of the dynamics of higher trophic levels is paramount, and is perhaps the greatest challenge facing the community of biological oceanographers and fishery managers.

Although significant capabilities exist to assess climate and the CCE from observations and models, most of these activities are uncoordinated. Coordination is critical because it allows comparison and connection between different regions and parts of the ecosystem within the CCE. Coordination is also necessary due to the large scale of processes and species distributions in the CCE, many of which transcend regional boundaries. Coordination of observing with model development will increase the rate at which we advance our understanding of climate impacts on ecosystems and our ability to predict and forecast for management needs under future climates.

Why

Society needs predictions of climate change effects on marine ecosystems to make management and policy decisions. We propose to meet that need through the plan presented here. Our plan is justified given society's needs in the face of impending change and our present inability to predict and forecast future ecosystem states, especially populations of higher trophic levels. To date, there are no dynamically coupled models from climate to such populations, let alone ecosystems. Yet, the need is large and growing for science-informed decisions concerning climate and marine ecosystems. Natural and anthropogenic climate changes are known to affect marine ecosystems. We lack the ability to forecast these effects for the CCE. Wise management and policy requires the best possible prediction of these effects to inform decisions. Scientific uncertainty causes risk to society, including economies, and thus must be reduced. We believe that our proposed CCE observing and phased development of models is the best way forward. The CCE is well studied, heavily used, strongly impacted by climate variability, and the focus of increasing attention at the local, state, and federal levels. An example is the West Coast Governors' Agreement on Ocean Health of September 2007, acknowledging the need for coordinated and collaborative coast-wide observing and research. We believe our plan is realistic and novel, brings together scientists, managers, and stakeholders, and will provide information

---

[9] http://www.ecopath.org/

needed to make management and policy decisions in a changing climate and in the context of the ecosystem.

Our specific objective is to **create a program of coordinated and sustained observing systems, and coupled physical-biological modeling in the CCE that will result in products to inform management.** This will be done using continued and new observations, in coordination with other observing programs and initiatives, especially IOOS[10], PaCOOS, and all west-coast regional associations. The models will range from statistical to dynamical and be developed by a diverse team of scientists, from academia, government, and industry, in a 'virtual modeling center', and include species of higher trophic levels. The result will be products, including improved assessments and forecasts, delivered to managers for use in making decisions in the context of climate and the ecosystem. The novelty of our proposal lies in the iterative development of increasingly capable models and their testing using coordinated observations. Key elements of our plan are the use of science working teams and peer review.

What

Observations

Extensive observations of the ocean and atmosphere in the CCE now exist and new technologies and programs are emerging. Of particular interest, in addition to existing air and sea measurements, are improved

a. estimates of winds and air-sea fluxes,
b. quantification of the sources of nutrients to the surface layer, especially as influenced by changes in stratification, the California Undercurrent, wind-stress curl, freshwater input, and bottom topography,
c. resolution of the spring transition, and
d. latitudinal spacing of routinely occupied cross-shelf transects.

These tasks will be accomplished through a coordinated observing program involving cross-shelf transects, moorings in both the northern and southern California Current system, and a set of autonomous glider lines. Besides these *in situ* measurements, we make special note of the need for continuity in satellite observations of ocean temperature and color, sea-surface height, and winds.

Biological observing also requires significant enhancement if reliable predictions and forecasts are to occur, particularly of higher trophic levels. This includes the distribution and abundance of zooplankton, especially euphausiids, and nekton, particularly the juveniles of exploited fish species, by use of advanced acoustic, optical, and net sampling systems; migration and connectivity of fish populations by use of tags and otolith chemistry; and population structure by use of molecular genetics. Biological sensor development is needed for inclusion on platforms including gliders, floats, moorings, and tags.

[10] Integrated Ocean Observing System (http://www.ocean.us/)

Process Studies

Specific needs of models will also be addressed by process studies. These include, but are not restricted to, vital rates and behavior of the mesozooplankton and higher trophic levels that are not routinely measured. Of particular interest are feeding, mortality, and patchiness for larger zooplankton, especially euphausiids, and nekton. Results from process studies will be used to develop and parameterize deterministic models that include higher trophic levels.

Modeling

Fisheries management in the context of the ecosystem and climate change requires a diversity of models of both the physical state of the CCE and selected trophic levels and taxa. We seek useful, verified biological forecasting tools, especially for populations of higher trophic levels. Statistical models, based on the past behavior of a system, will continue to be used, particularly for higher trophic levels, until mechanistic models are developed. Ecological indicators will be developed based on observations and models; see, for example, ocean indicators for marine salmon survival in the northern California Current[11]. Dynamical models are progressing to include populations of organisms such as mesozooplankton and fish, which have complex dependencies on age structure and feeding, migration, aggregation and other behaviors.

For models to address the wide range of phenomena in the CCE, we propose a toolbox with a diversity of models. This will include statistical models, for now-casting and near-term prediction, and dynamical models, for longer-term prediction. Forcing will be from past climate, e.g. re-analyses, and future climate, e.g. from regional scenarios of AOGCMs run at GFDL[12]. Sets of biological models will be developed that focus on combinations of trophic level, taxon, and size. Of especial interest are IBMs (which can include behavior) and the NEMURO[13] model (which includes many trophic levels from phytoplankton to fish) developed by PICES[14] scientists.

We propose a "Virtual Modeling Center", comprised of scientists working in a variety of locations and institutions, including NOAA, academia, and industry, in which ideas, labor, and products will be developed and shared. Development and implementation will occur in phases:

a. Interim - Before funding, existing resources will be assessed. Deterministic models with regional physics, phytoplankton, and small zooplankton will continue to be tested. An extensive set of community modeling tools, such as data sets for model forcing and testing, will be developed.
b. Five years – Develop dynamical models including behavior of larger zooplankton. Parameterize and test these using specific observations and process studies. Improve statistical models of fish populations and their variability as influenced by climate. Begin development of dynamical models of populations managed by NOAA.

---

[11] http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm
[12] http://www.gfdl.noaa.gov/
[13] North Pacific Ecosystem Model for Understanding Regional Oceanography
[14] North Pacific Marine Science Organization (http://www.pices.int/)

c. Ten to Twenty years – Refine and test dynamical models of populations managed by NOAA, including exploited species, in the context of the ecosystem and climate, and accounting for behavior (e.g., feeding, migration and aggregation).

Forecasting

Our goal is to better inform managers. The proposed observations and models will enable forecasts, initially in a research mode and ultimately in an operational mode. Forecast skill will be evaluated, much like for weather. Risk and uncertainty will be explicitly treated. It is likely that forecasts will be probabilistic rather than deterministic. A range of operational products will be sought, from short-term, statistically based forecasts with narrow probability distribution functions (pdfs), to longer-term, dynamically coupled models based on AOGCMs, box models, and IBMs, yielding pdfs that broaden as the prediction lengthens.

Integrated Ecosystem Assessments

Although it is not clear at this time who will be responsible for Integrated Ecosystem Assessments (IEAs) for the California Current, we will be well positioned to both contribute to such efforts as well as be directly responsible for them. Examples of different approaches to an IEA include the annual CalCOFI State of the California Current and the assessment of ocean conditions off British Columbia produced by the Canadian Department of Fisheries and Oceans[15].

Who and Where

The proposed work will be carried out by a partnership of government and academia. The Northwest and Southwest Fisheries Science Centers and academic partners from Washington to California will be involved. Coordination will also involve our scientific partners in Canada and Mexico. A distributed work model will be used. Science Working Teams will be formed and modeled after similar teams in NASA. Members will be from academia, government, and interested stakeholders, and include observationalists and modelers. Five-year projects will be selected and overseen by Science Working Teams using peer review. Separate teams will be tasked with overseeing observing, process studies, and modeling. This approach clearly addresses NOAA's need to take a region-specific collaborative approach to ecosystem-based management. Moreover, the need to develop integrated regional and scalable assessments and forecasts of ecosystem health and productivity can only be done successfully through use of a consortia of scientists and agencies who are committed to sustained observations and modeling.

When

Climate and ecosystem observing and models will be developed simultaneously and in close coordination. During FY10-14, the proposed transect lines, mooring and glider deployments, and analyses of targeted fish populations will be initiated. We will build on the existing west-coast observing and data management systems inaugurated by PaCOOS. Particularly pressing is the

[15] http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/StateofOceans2005fnl.pdf

need to establish sampling lines off Washington and northern California. By FY14 we expect a coordinated observation program across the CCE including both physical and biological measurements, shared through a readily accessed web portal. Under existing modeling programs, we will continue to test deterministic models, including those that include small zooplankton. In the first five years of funding, we will incorporate mesozooplankton in deterministic models and improve statistical models of fish. Our 10-20-year goal is to develop deterministic models and forecasts for components of the CCE managed by NOAA, i.e., populations of higher trophic levels.

Resources

The proposed program of observation, process study and modeling is estimated to require $5M per year for the first five years. Resources will be distributed among both government and academic laboratories. Activities will include observations (cross-margin transect lines, gliders, moorings, and NOAA and State fish surveys), biophysical and ecosystem modeling, data management, and preparation of ecosystem indicators and ecosystem status reports.

Benefits

The impact of the work we propose will be to improve decisions made by managers and policy makers. Presently, our ability to forecast and predict future states of marine populations and ecosystems is very limited. Future decisions in the face of unprecedented change requires a mechanistic understanding of the effects of climate on ecosystems. We seek such an understanding and simultaneously the most effective means to inform management. Thus, the impact of our work will increase with time as, for example, we enhance our observing and shift from statistical to deterministic forecasting and prediction, particularly for populations of higher trophic levels.

We acknowledge that what we propose is challenging. A significant risk, and perhaps barrier, is the deterministic modeling of the dynamics of higher trophic level populations. This is due largely to behavior being increasing important to dynamics with increasing trophic level. Similarly, regionalization of ocean and climate models is challenging. In both cases, however, significant progress has recently been made. Biophysical and individual-based models show promise for modeling higher trophic level populations and global models are now being run, for example at GFDL, with regional outputs. There may be inherent limits to our ability to predict future states of both physical and biological systems, including managed populations. At such limits, it may be necessary to continue to base forecasts and predictions on statistical rather than mechanistic models. However, we believe we are far from this limit, if it exists, and that the work we propose is justified.

We depend, to varying degrees, on other programs on observing and modeling. We propose to build on and collaborate with existing and future programs in both areas. As described above, an extensive patchwork of observing programs now exists. Large, coordinated observing systems, including IOOS and PaCOOS, will provide needed and valuable observations. We also depend on climate and ocean models, particularly those that move from the global to the regional scales.

We reiterate that we believe that significant effort is underway in both of these areas, and that close collaboration with each is the best way forward.

Beneficiaries

Primary beneficiaries include the Pacific Fishery Management Council (PFMC) and stock assessment teams actively involved in the management of sardine (Coastal Pelagic Species FMP[16]) and hake (West Coast Groundfish FMP and the U.S./Canada agreement on the management of hake). In addition, the PFMC is developing management measures to regulate directed fisheries for krill and recently passed an amendment within the Coastal Pelagic Species FMP that bans its harvest. The hake work will be a direct economic benefit for the industry because if the proportion of hake in the Canadian zone could be predicted, industry could prosecute the fishery more efficiently. The California Department of Fish and Game manages the market squid (Market Squid FMP). Salmon harvest management is heavily dependent upon the development of better one-year forecasts of salmon returns, particularly since the "tried and proven" methods employing the Bakun upwelling index no longer provide accurate forecasts. Protection and recovery of endangered species, from fish to marine mammals, under climate change will benefit from our proposed work. The observations, models, and indicators which we will develop will also benefit NOAA/Oceans coastal activities, including the management of west-coast NMS[17] and NERRS[18], and will benefit those who manage marine reserves. Our data and models will also prove useful for the prediction of harmful algal blooms and hypoxia and their effects. Monitoring sentinel species will provide NOAA climate scientists with a new way of detecting climate change. Technological improvements can be applied to other regions and projects for monitoring the oceans (e.g., IOOS). Finally, ecosystem-based management and policy, particularly in the context of fishing and climate change, will be enhanced with the products we propose to develop and deliver.

[16] Fisheries Management Plan
[17] National Marine Sanctuaries (http://sanctuaries.noaa.gov/)
[18] National Estuarine Research Reserve System (http://www.nerrs.noaa.gov/)