# Table of Contents

Table of Contents ....................................................................................................................... i

Scientific/Technical/Management Section

Introduction ................................................................................................................................. 1
Background - Decision Making Past, Present and Future .......................................................... 2
The 2004-2007 anomaly .......................................................................................................... 4
Integrating NASA Earth Science with Ecosystem Models ...................................................... 5
  1. Integrate data with basin-scale coupled physical-biological models .......................... 6
  2. Identify mesoscale oceanographic features .............................................................. 10
  3. Quantify the spatial relationships between oceanography, primary production and observed production of krill, rockfish, and seabirds .... 11
  4. Apply these results to salmon assessment and management .................................... 13
Benefits to NASA and Society ............................................................................................... 13
Project management ............................................................................................................... 14
References and Citations ............................................................................................................. 16

Biographical Sketches ................................................................................................................. 19

Current and Pending Support ....................................................................................................... 34

Statements of Commitment and Letters of Support ................................................................. 42

Budget Justification: Narrative Details ....................................................................................... 53
**Introduction**

Conventional wisdom once suggested that ecological conditions in the riverine environments that support salmon spawning determine variability in population abundance at return. More recently, however, it has been recognized and widely accepted that the ocean plays a critical role in determining salmon returns and fisheries catch (Mantua et al. 1997). In particular, the abundance of food (e.g., zooplankton) during the initial months of ocean life, when the salmon are small and most susceptible to predation, affects the at-sea survival of salmon as they first migrate to the sea and ultimately changes in populations years later when cohorts return to spawn. In the Pacific Northwest, and upwelling driven ecosystem, correlations between upwelling indices and Chinook salmon returns to the Columbia River system support the hypothesis that food availability and salmon returns are coupled (Scheuerell & Williams 2005). Other physical oceanographic indices that relate to robust food webs, for example the timing of the spring transition, also are important (Logerwell et al. 2003). More direct evidence on the importance of food during the initial phase of salmon at sea comes from analysis of Coho salmon returns to Oregon hatcheries. In examining the relationship between 3 species of “boreal” copepod and coho returns, Peterson & Schwing 2003 documented a non-linear (“s-shaped” logistic) relationship between coho returns and this food web index off Oregon. Unfortunately, the non-linearity of this relationship compromises its utility as a predictor, since at both low and high levels of abundance of boreal copepods, coho returns showed little change. Nonetheless, this index explains a relatively high proportion of the variability in Oregon coho returns ($r^2 = 0.5$). Similarly, Wells et al. (2008) developed an index of ecosystem state for central California, developed from estimates of krill, juvenile rockfish, and seabirds, that is highly correlated with Central Valley (Sacramento River) salmon catch and returns ($r^2 = 0.71$). These *food web indices* are new, but with a better decision-support system in place, the overarching goal of our project, with these empirical-statistical models we could have better anticipated the remarkably low returns observed for Chinook salmon in 2007 which resulted in the fisheries closure for 2008 and financial hardship for many coastal communities along the U.S. West coast. We strive to improve both the ecological and economical sustainability for salmon in this region.  

Food web modeling, and more generally ecosystem modeling, has advanced greatly in recent years, and now offers a unique and compelling opportunity to improve salmon management in the California Current Large Marine Ecosystem. As such, we propose to integrate the Regional Oceanographic Modeling system (Shchepetkin and McWilliams, 2005), well-established empirical-statistical approaches (e.g., Wells et al. 2008), comprehensive ecosystem models (Chai et al. 2002), and individual-based modeling (IBMs) to enhance our knowledge of salmon survival at sea and ability to forecast population dynamics. To accomplish this objective, we will combine two veteran research teams with decades of experience with the underlying goal of improving the existing decision support system for central-northern California salmon management. The teams include fisheries scientists and oceanographers of the National Marine Fisheries Service (NMFS) focused on salmon biology, ecology and management (B. Wells, team leader) and a group with a long-standing track-record of working with NASA remote sensing, ROMS, and ecosystem models (F. Chavez, team leader). For this project, we initially evaluated the “Research and Data Needs of the End-Users”, a document of the Pacific Fishery Management Council which outlines needs in terms of enhanced decision-support tools. In short, this document highlights better precision and timely forecasts of salmon to (1) maintain the long-term sustainability of fish populations, (2) better protect the ecosystem of which the fish
are an integral part, and (3) maximize social and economic benefits and prevent wasteful over-investment of economic resources. Our proposal addresses these fundamental needs of the Pacific Fisheries Management Council (PFMC), which will enhance ecosystem-based stock assessments, harvest control rules (quotas) and the information for assessing the viability of threatened and endangered salmon stocks under the Endangered Species Act (ESA).

The specific goal of the proposed research is to quantify and model, in a predictive manner, the mechanisms that force productivity in the central California coastal waters and apply those results to better forecasting and management models of Central Valley Chinook salmon. This goal will be accomplished by combining oceanographic models that incorporate remotely-sensed environmental data to predict the degree and distribution of primary production within the central California coastal waters and empirical data on the distribution and production of krill, rockfish, and seabirds. Once the mechanisms driving production in the region are quantified the results can be extended to better management of Chinook salmon temporally and spatially.

Background - Decision Making Past, Present and Future

The PFMC is charged under the Magnuson Fishery Conservation and Management Act (MSFCMA) of 1976 with managing fisheries from 3-200 miles offshore of the coasts of California, Oregon, and Washington, including some endangered stocks of Chinook salmon from California’s central valley. Each year, PFMC must decide on harvest limits which are consistent with the sustainability requirements of the MSFCMA and Endangered Species Act (ESA). Harvest limits and listing/delisting recommendations are, in large part, determined by “escapement” (the number of fish returning to spawn) goals of the PFMC’s Salmon Technical Team (STT). In 2007, adult Chinook salmon returns to the Sacramento River watershed were the second lowest on record, falling well-below the escapement goals for this population. This prompted severe management actions, as well as a great deal of speculation into possible causes. In response to the unpredicted and precipitous decline, the PFMC closed the fishery for the 2008 season, the most drastic management measure in the history of West Coast salmon fisheries. The economic impact of this decision to California alone is projected to be approximately $255 million, with a loss of ~2,260 industry-related jobs (Gov. Arnold Schwarzenegger, 2008).

This management decision resulted from the fact that the declines were substantially worse than current models predicted. Current management models for Chinook salmon are based on maintaining a large enough population of 3 year old and older salmon in the ocean to assure that enough fish return to spawn to maintain the population. Specifically, once an estimate of the number of adult fish in the ocean is determined from current cohort models, and it is demonstrated that there are enough to maintain a large enough breeding population, the remainder are open to fishing (i.e., quotas are set on the fishery to maintain an acceptable breeding population). The estimate of adult ocean abundance is therefore critical to management. In 2007, the model used by the PFMC overestimated the abundance of central valley Chinook salmon by 116%. The forecast for 2007, using the PFMC model was 499,900 fish which was 2.16 times greater than the 232,000 observed. Clearly, new methods are needed to enhance forecasting capabilities, especially during times of substantial ecosystem change. In particular, it appears that trophic (i.e., feeding) interactions for salmon and other species (e.g., seabirds and marine mammals) at sea in the California Current have been disrupted in recent years, which are hypothesized to have lessened productivity and survival.
Well before the salmon collapse of 2007, in an attempt to improve management and decision systems, the PMFC conducted a Research and Data Needs review, concluding that there was a need to move towards an Ecosystem-Based Fisheries Management framework\(^1\). This new approach would involve both temporal environmental and spatially-explicit information:

"(a) Increasing use of short and long term climate and ocean status, trends, and scenarios for the California Current ecosystem in stock assessments, harvest levels and rebuilding plans, (b) consideration of trophic interactions among species, both fished and unfished, and the associated impacts of fishing on trophic dynamics and ecosystem structure and function, (c) the increasing application of new management approaches, including spatial management measures to protect life history characteristics, biodiversity, and complex stock structure."

In addition, specifically for salmon, the Research and Data Needs Review concluded that the management would be enhanced by “identification of key physical and biological indicators for prediction of salmon early ocean survival”…as well as “development of probabilistic habitat-based models that incorporate environmental variation…”

As noted above, a primary component of the annual decision support system, for salmon management involves forecasting abundance of fish at sea (known as the CVI or Central Valley Index). The STT of the PFMC has used and evaluated several predictors of the CVI since 1985, but since 1991 has used a linear regression of the previous year’s \((year\ x\ -\ 1)\) Central Valley age-two precocial male returns (“jacks”) to predict the following year’s catch and escapement. From 1985-2007, the forecast has ranged from 0.49 to 2.16 times the actual value (Figure 1). Due to recent changes in the rate at which precocial males are returning, the STT is currently considering a different prediction method (PFMC 2008).

Notable years include the estimate of ocean abundance for 2005, which according to current models should have been one of the most abundant years on record but ultimately returns

---

indicated that it was average at best (Figure 1). The “jack” model has continued to overestimate ocean abundance through 2007, the same time period during which oceanographic dynamics of the central California coast have been highly anomalous (Figure 2). While recent overestimates have not been as severe as that for 2005, they have occurred at a time when the population is severely depressed; hence, there is little room for error in a management context.

Given the current situation, we propose to enhance forecasting models and quantify the relationships between mesoscale oceanographic features and productivity of the central California coast, which is the region that newly emigrated Central Valley Chinook salmon occupy, thereby improving the existing decision support system (DSS) for salmon management. To accomplish this, we will incorporate spatially-explicit, ecosystem based nowcasts and forecasts of oceanographic conditions and their model impact on ocean salmon survival. Our proposed work would incorporate available in situ data, information from space-based real time sensors, high-resolution coupled physical-biological models, and improvements in ecosystem theory into these basic management models. The proposed DSS improvements will result in improved estimates of ocean salmon abundance, allowing for better management forecasts. In addition, this information will improve the current framework for assessing the viability of threatened and endangered salmon with regards to status under the ESA.

**The 2004-2007 anomaly**

The poor escapement of salmon in 2007 and resulting fisheries closure in 2008 are clearly related to a period of anomalous ocean conditions in the California Current which began in 2004 and continued at least through late 2006 or early 2007. These anomalies are reflected in a wide variety of physical (temperature, salinity, wind) and biological (phytoplankton and zooplankton species, sebird reproductive capacity, salmon abundance) properties. Recent work by Wells et al. (2008) indicates that local oceanographic and production variability in central California has diverged from the larger California Current system as indexed by the Northern Oscillation Index (Figure 2) and these divergent conditions resulted in poor production of the regional ecosystem and increased early mortality of emigrating salmon. Specifically, examination of ecosystem and oceanographic conditions demonstrates that the wind patterns along the central California coast...
have been anomalous during these years. Previous work has suggested that changes in winds affects nutrient input and/or ocean transport processes (retention and/or offshore advection). In both cases, this would lead to reduced prey availability, which in turn could affect the foraging success, breeding success, and survival of top predators, like salmon and seabirds in the region. Evidence suggests that this was the case for seabirds in 2005-2007 (Sydeman et al. 2006, Peterson et al. 2007, Goericke et al. 2008). Moreover, there is evidence that salmon returns and seabird breeding success show in phase (positive) co-variation in this system (Roth et al. 2007). Mechanistically, however, the effects of changes in wind fields and food web dynamics in the region are poorly understood. Changes in wind patterns could affect nutrient input and primary productivity, aggregation/concentration of seabird and salmonid prey, and the foraging success of these top predators. Preliminary evidence suggests that it is changes in wind-stress curl (Wells et al. 2008) that is leading to lessened spatial and temporal overlap between predators and prey in the system. This project will focus on establishing the exact mechanism.

Importantly, identifying and quantifying the mechanisms that link the abundance and availability of primary production and prey distribution and abundance to top predators is clearly a key element of an ecosystem-based approach to management (EBM). As a demonstration of the importance of this proposed work we have incorporated, here, the results from Wells et al. (2008) into the current jack model to better fit Central Valley salmon abundance over the last 15 years (Figure 1). These results demonstrate two important points: (1) the oceanography of the central California coast has dramatic affects on the dynamics of salmon emigrating into the region and (2) better forecasting estimates can be obtained by incorporating data on oceanography, krill, rockfish, and seabird dynamics. Unfortunately, the fit we present in Figure 1 is simply a correlation and is bound to fail without the inclusion of mechanisms into the model. For instance, if we extend this model to data prior 1993 the fit is dramatically inferior to that shown here. By extension, it is likely that in future years, as data is added to the series, the relationship will fail. Here, we intend to quantify the links between regional and mesoscale (e.g., front developments) oceanography and salmon production in the region by examining the relationships between each successive step in the trophic chain.

**Integrating NASA Earth Science with Ecosystem Models**

We have available long-term empirical databases in the region, including an unparalleled 23+ year (1983-present) time series of hydrographic and biological conditions as part of the NMFS Juvenile Rockfish Survey additional *in situ* data from an intensive MBARI time series (http://www.mbari.org/bog/mb/Interannual.htm), a repeated hydrographic survey along CalCOFI Line 67 by ships and more recently gliders (http://www.mbari.org/bog/glider), and a wide variety of newly available remotely sensed data from NASA (See Tables 1 and 2). The fundamental approach will be to integrate these data in new ways to enhance forecasting capabilities for salmon.

More specifically, we propose to enhance forecasting capabilities for salmon abundance at sea (and improve estimates of salmon ocean survival) by integrating food web information from the NMFS juvenile trawls surveys with measurements of oceanography and oceanographic change using the Regional Ocean Modeling System (ROMS) and numerical modeling of ecosystem dynamics. The food web will be relatively simple, but focused on key attributes and prey species of salmon, including estimates of primary productivity, krill (euphausiid) productivity and
distribution, and juvenile rockfish productivity and distribution. We will relate these food web constituents to salmon and seabird production temporally (emphasizing the years 1997 – 2007, in accordance with the years of quality NASA satellite products) and spatially within the central California coastal habitats. Notably, to our knowledge this will be the first spatially-referenced ecosystem-based forecasting models for salmon. Once completed, we will offer this “toolbox” and educate end-users (managers), through targeted outreach to the PFMC (and the North Pacific Fisheries Management Council, if possible) and demonstrate improved year-to-year forecasting of salmon.

To meet the overall goal of this work we propose will be in four steps: (1) integrate data with basin-scale coupled physical-biological models, (2) identify mesoscale oceanographic features within central California, (3) quantify the spatial relationships between oceanography, primary production and observed production of krill, rockfish, and seabirds, and (4) apply these results to salmon assessment and management. These components will be discussed in succession here.

(1) Integrate data with basin-scale coupled physical-biological models
To achieve our goal of deriving spatially and temporally robust relationships and forecasts, we anticipate using a wide array of synoptic earth observing products and derived indices, empirical measurements of the food web and ecosystem, and derived products from numerical models. In addition to the basic products derived from satellite or models, the Environmental Research Division (ERD) of NOAA’s Southwest Fisheries Science Center supplies derived products developed in conjunction with operational data users. These include: (1) vertically integrated primary productivity fields, derived from surface chlorophyll-a and sea surface temperature (SST) (after Behrenfeld and Falkowski 1997); (2) the Front Probability Index from GOES sea surface temperature (following Breaker et al. 1995), which will be used to identify zones of potential biological interactions; and (3) maps of potential Chinook salmon habitat derived from satellite-derived sea surface temperature and electronic tags placed on Chinook salmon in the ocean (Hinke et al., 2005a, Hinke et al., 2005b; shown in Figure 3). Our efforts will incorporate not only mesoscale spatial habitat variation and environmental conditions, but also associated prey abundance and distribution, in mapping optimal habitat for salmon -- and other top predators (seabirds) in this system. In addition to the near real time products, ERD maintains online historical archives of “climatology”, analogs for each parameter through time, that will allow us and the decision makers place the present conditions within the context of long-term dynamics of the region. Table 1 provides a list of the products derived from satellite and models to be used in this project.
Figure 3. Maps integrating satellite SST and fish tag data to demonstrate inter-annual variability in Chinook surface habitat in northern California and southern Oregon.

Table 1. List of environmental parameters to be used in this project. The Aquarius spacecraft is not due to launch until 2010; however, our system will be configured to accommodate the data stream when it becomes available.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dependencies</th>
<th>Source</th>
<th>Provider</th>
<th>Latency</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll a</td>
<td>nLₐ(l)</td>
<td>Orbview-2/SeaWiFS</td>
<td>Geoeye Inc.</td>
<td>18 hours</td>
<td>1997 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqua/MODIS</td>
<td>OSU</td>
<td>3 hours</td>
<td>2002 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ROMS/CoSINE</td>
<td>JPL/Maine</td>
<td>3 hours</td>
<td>1975 - now</td>
</tr>
<tr>
<td>K₄₉₀</td>
<td>nLₐ(l)</td>
<td>Aqua/MODIS</td>
<td>OSU</td>
<td>3 hours</td>
<td>2002 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquarius</td>
<td>JPL</td>
<td>Unknown</td>
<td>2010⁴</td>
</tr>
<tr>
<td>Salinity</td>
<td>Undetermined</td>
<td>ROMS</td>
<td>JPL</td>
<td></td>
<td>1975-now</td>
</tr>
<tr>
<td>Sea Surface Temperature</td>
<td>Good cloud</td>
<td>Aqua/MODIS</td>
<td>JPL</td>
<td></td>
<td>2002 - now</td>
</tr>
<tr>
<td>and land masks</td>
<td></td>
<td>Aqua/AMSR-E</td>
<td>RSS Inc.,</td>
<td>12 hours</td>
<td>2002 - now</td>
</tr>
<tr>
<td>Wind Vectors</td>
<td>Good rain flag</td>
<td>QuikSCAT/Seawinds</td>
<td>JPL</td>
<td>6 hours</td>
<td>1999 - now</td>
</tr>
<tr>
<td>Primary Productivity</td>
<td>Chlorophyll a</td>
<td>Aqua/MODIS</td>
<td>CoastWatch</td>
<td>18 hours</td>
<td>1997 - now</td>
</tr>
<tr>
<td></td>
<td>SST</td>
<td>Aqua/MODIS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insolation</td>
<td>Orbview-2/SeaWiFS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FrONTAL Probability</td>
<td>SST</td>
<td>Aqua/MODIS</td>
<td>CoastWatch</td>
<td>18 hours</td>
<td>2001 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GOES/Imager</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea surface height</td>
<td>Good</td>
<td>Jason -1</td>
<td>FNMOC</td>
<td>2 days</td>
<td>2001 - now</td>
</tr>
<tr>
<td></td>
<td>Navigation</td>
<td>Jason -2</td>
<td>NOAA</td>
<td>1 day</td>
<td>2008 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ROMS</td>
<td>JPL</td>
<td></td>
<td>1975 - now</td>
</tr>
<tr>
<td>Thermocline deviations</td>
<td>SST</td>
<td>Aqua/MODIS/AMSR</td>
<td>CoastWatch</td>
<td>2 days</td>
<td>2001 - now</td>
</tr>
<tr>
<td></td>
<td>SSH</td>
<td>Jason-1, Jason-2</td>
<td>FNMOC</td>
<td></td>
<td>1975 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ROMS</td>
<td>JPL</td>
<td></td>
<td>2002 - now</td>
</tr>
<tr>
<td>Eddy Kinetic Energy</td>
<td>SSH</td>
<td>Jason-1, Jason-2</td>
<td>CoastWatch</td>
<td>1 day</td>
<td>1975 - now</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ROMS</td>
<td>JPL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The primary tool from which our biological data comes is the spring mid-water trawl and bird observation cruise conducted on board the NOAA Ship *David Starr Jordan* along the central California coast from Point Reyes to Monterey Bay, CA (Figure 4, Table 2). The replicate years available are 1983 - 2007.
Figure 4. Shows the sea surface temperatures collected during a typical NMFS cruise pass during the upwelling season along central California. Black square represents the location of the Farallon Islands. Dots represent NOAA David Starr Jordan core mid-water trawl stations.

Table 2. Biological time series and references indicating data assimilation and analysis procedures.

<table>
<thead>
<tr>
<th>Trophic level</th>
<th>Collection tool</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krill</td>
<td>Simrad EK 500, continuous sampling</td>
<td>Demer and Conti 2005</td>
</tr>
<tr>
<td>Rockfish juveniles</td>
<td>Mid water trawl, 37 sampling stations (Figure 1)</td>
<td>Sakuma and Ralston 1995</td>
</tr>
<tr>
<td>Seabird foraging</td>
<td>Day-time onboard observations</td>
<td></td>
</tr>
<tr>
<td>Seabird productivity</td>
<td>Breeding colony observations of fledgling rate</td>
<td>Sydeman et al 2001</td>
</tr>
</tbody>
</table>

Despite the benefits attendant in large-scale oceanographic satellite measurements, they suffer from the limited variety of bio-physical parameters that can be measured from space, relatively low accuracy of those measurements, and the general inability to see below the ocean surface. Therefore, to complement NASA based satellite surface observations, we will integrate in situ biological measurements from NOAA NMFS surveys and 3-dimensional ocean circulation modelling, with data assimilation (Figure 5), to complete the oceanographic-ecological-salmon integration. This modeling team has a long history of successful model development for ecological applications, including projects that have been funded by NOPP (http://www.mbari.org/bog/NOPP/default.htm), IDS and more recently NASA Applications (http://www.mbari.org/bog/fast). The goal is to reproduce, in hindcast and forecast modes, the central California Current ecosystem dynamics and variability associated with salmon abundance. As noted above, the proposed modeling component will be based on the Regional Ocean Modeling System (ROMS) a community model originally designed for regional applications (Shchepetkin and McWilliams, 2005). In addition to its numerous regional applications, ROMS is also configured for the Pacific basin (Wang and Chao, 2004) and Atlantic basins (Chassignet et al., 2000). Funded by the NASA Interdisciplinary Science program, a 3D Pacific basin-scale ocean circulation model has been developed with a spatial resolution of 50
km. With the recent installation of the Columbia supercomputer at the NASA Advanced Supercomputing Division (ranked as the #2 supercomputer in the world), the spatial resolution of this Pacific ROMS has been increased from 50-km to 12.5-km, approaching eddy-resolving resolutions and the proper resolution with which to examine salmon habitats in this system and region. At this eddy-resolving resolution, simulation of key oceanographic processes, food web dynamics and predator-prey relationships can be significantly improved.

Figure 5. Snapshot of a simulation by the 12.5-km Pacific basin-scale ROMS 3D ocean circulation model; shown are sea surface temperatures (in color) and sea level slope (shaded relief). The model is capable of reproducing Tropical Instability Waves (TIWs) as well as mesoscale eddies near the western and eastern boundary currents.

While the Pacific ROMS model covers a region from 45°S to 65°N and from 99°E to 70°W, clearly more than is needed for improving salmon management in the PFMC region, an analysis of the 12.5 km model shows that it can capture ENSO variability very nicely (Figure 6), and it is well known that ENSO variability affects the salmon food web, including krill, juvenile rockfish, juvenile hake, and market squid in the region of interest. This highlights the value of the 12.5 km resolution model to this project. This high resolution ROMS model has been coupled to an ecosystem (NPZ) model. The ecosystem is the Carbon, Si(OH)₄, Nitrogen Ecosystem (CoSINE) model developed by Chai et al. 2002. The CoSINE model includes silicate, nitrate, oxygen, inorganic carbon and ammonium, two phytoplankton groups, two zooplankton grazers, and two detrital pools. To benefit salmon management, the outputs of this model will be used to predict krill, forage fish (rockfish and hake) and market squid. Predictions will then be compared to salmon abundance.

As part of the NASA/FAST project, the basin-scale Pacific simulations have been and will continue to be performed through 2009. These simulations include a 50 year, 50 km resolution hindcast (NCEP forcing), a 20 year 12.5 km hindcast (NOAA blended wind, that incorporates satellite-derived winds, forcing) and 9 month, 12.5 km forecast (NCEP forecast forcing). Forecasts for several years starting in ~2000 (with starts in January and July) have been carried out to validate the ability to forecast. To date, such analyses have focused on the Peru Current; output for the California Current have only been partially validated, but appear promising. As part of the present proposal, we will analyze the available hindcasts and forecasts as well as continue the forecasts through 2011. For Peru reliable forecasts for chlorophyll are have been made 5 to 6 months in advance. Importantly, anchoveta recruitment and SeaWiFS chlorophyll (March-April) for Peru are highly correlated suggesting that forecasting of successful forage fish year classes for top predators in the California Current may be possible. We will forecast the food web indices for salmon in a similar manner, and compare them with empirical data based
(2) Identify mesoscale oceanographic features
Bulk statistical properties such as eddy kinetic energy can be used to infer the location and persistence of dynamic eddies, jets and meanders typical of the California Current system (CCS), and undoubtedly of great importance to salmonid feeding ecology. Once such features are identified, we can not only conduct a census of such features, but also evaluate their ecological impact by using locations to extract other available properties such as chlorophyll concentration, temperature and mesoscale currents. For example, individual eddies can be identified in the CCS with data from satellite altimeters or ROMS using the Okubo-Weiss parameter, \( W \) (Okubo, 1970; Weiss, 1991), which measures the balance between strain and enstrophy in the surface currents. \( W \) is expressed in terms of the shear strain, \( s_s \), the normal strain, \( s_n \), and the vorticity, \( \omega \):

\[
W = s_s^2 + s_n^2 - \omega^2 .
\]

The strain components and vorticity are in turn calculated using geostrophic current components \( u \) and \( v \) derived from maps of sea level, \( h \), and the Coriolis parameter, \( f \), (e.g., Isern-Fontanet et al., 2004; Henson and Thomas, 2008),

\[
s_s = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} ,
\]

\[
s_n = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} ,
\]

\[
\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} .
\]  

\[
u = -\frac{g}{f} \frac{\partial h}{\partial y} ,
\]

\[
u = \frac{g}{f} \frac{\partial h}{\partial x} .
\]

Large negative values of \( W \) typify the eddy core, with smaller, positive \( W \) in the strain-dominated rings of the eddy. Once identified, these eddies can then tracked through the successive weekly images using custom-built image recognition routines in Matlab (Henson and Thomas, 2008).
Our proposed work will include the development and testing of tools for the identification of irregular oceanic features such as jets and meanders. The most promising method thus far explored involves the use of 2-dimensional wavelet analysis, though other options will be considered. Once developed, the tools will be tested on both the modeled fields as well as satellite data sets, with the intent of providing the capacity to automatically detect a number of typical “events”. This could serve as a basis for notifying resource managers of habitat variances, as well a method to effectively filter and compress the huge data sets produced by modern coastal models.

(3) Quantify the spatial relationships between oceanography, primary production and observed production of krill, rockfish, and seabirds

In addition to the temporal and spatial modeling described above, we propose to develop spatially-referenced empirical indices of ecosystem state based on the production and distribution of primary production, prey, and predators in the region. One of the difficulties here is that the distribution of salmon at sea is hard to study. As such, we will use seabirds as surrogates for salmon. Seabirds, notably planktivorous aukslets and piscivorous murres, co-vary in abundance with salmon (Roth et al. 2007, Sydeman et al. 2008) and show substantial dietary similarities (Mills et al. 2007 and references therein), including consumption of the prey species identified earlier in this proposal. We will accomplish the goals of this work through examination of spatial and temporal overlap of predators and prey as these reflect probable trophic interactions and food web dynamics. Specifically, we will focus on krill distribution and production as indirectly and directly krill form a keystone species in this system (Field and Francis 2006, Figure 7). Krill are a dominant prey item for juvenile rockfish, market squid, hake, and young salmon in this region, as well as key to adult salmon and seabirds (e.g., Sydeman et al. 2001). Moreover, persistent use of foraging areas by highly visible seabirds likely represents the habitat and underlying food webs that are also important to salmon (Batchelder et al. 2002). The oceanographic processes that affect the distribution of seabirds (and presumably salmon) will inform us about ecosystem state and the environmental mechanisms forcing production of the system as a whole (sensu 'trophic equivalents', Roth et al. 2007, Sydeman et al. 2008).

Predators are expected to be associated with prey according to an aggregative response (Holling 1965). For example, juvenile rockfish have been shown to aggregate along the shoreward side of temperature gradients (i.e., fronts; Sakuma and Ralston 1995; Bjorkstedt et al. 2002) where they feed on krill and provide a food source for predators. Persistent use of foraging areas by piscivorous seabirds has also been shown to be based on the persistence of aggregated prey (Weimerskirch 2007). During upwelling, prey aggregate along fronts and the birds go to those fronts preferentially to feed. When there is limited upwelling the prey are more diffused in the region. Typical responses to diffused prey include greater foraging distances (Monaghan 1996). In fact, when upwelling in the region is reduced, seabirds forage closer to shore, likely following the weak frontal waters that are typically associated with the shelf break farther off shore (Oedekonen et al. 2001 Yen et al. 2004, Ainley et al. 2005). This course-scale examination of habitat quality merits further investigation to determine the mechanisms and improve development of natural and easily available indicators of ecosystem productivity across trophic levels, with implications for salmon population dynamics.
Krill-Rockfish-Seabirds: We will provide the first ever synthesis of simultaneous mapping of krill patches and foraging seabirds for use in building predictive models for use in advising management. Changes in the spatial distribution of krill may have significant impacts on foraging and reproductive success of krill-dependent predators (Agnew and Phegan, 1995; Marin and Delgado, 2001, Santora et al. in press), such as seabirds and salmon. It has been postulated that an increase in prey patchiness should increase the foraging success of seabirds and other predators, whereas a decrease in prey patchiness may force predators to switch to other prey items (Fauchald et al. 2000, 2002). The California Current is a novel ecosystem for examining seabird foraging dynamics and krill patch distribution. Differences in foraging location should be examined to understand how spatio-temporal factors influence where seabirds choose to forage. Here we propose to examine the patch distribution of krill and seabirds to build models for predicting inter-annual changes of patchiness of krill and foraging seabirds, as surrogates for salmon. We provide some preliminary results of mapping for krill patches and foraging seabirds to demonstrate the dynamic variability of patchiness among 3 years in the central California Current region (Figure 7). In total, we sampled approximately 4000 nautical miles of cruise trackline per year for mapping krill patches. It is evident that the spatial distribution of krill patches varied considerably during 2004-2006 (Figure 7). Krill patches were distributed throughout the shelf-break region (primarily along the 200m isobaths) west and south of the Farallon Islands and south to Monterey Bay during May-June 2004 and 2005. However, there was a marked decrease in the patch structure of krill in 2006 whereby krill were patches found in limited quantity. Spatial distribution of foraging Cassin’s Auklets, which predominantly feed on euphausiids, shows a decline in foraging distribution and a shift towards the south. We plan to examine more years to quantify how changes in spatial distribution of primary production, krill patches, rockfish distributions, and seabird behavior are related to climate variability and ultimately salmon dynamics.

Figure 7: Distribution and abundance of acoustically determined krill (NASC/nmi) (top panels) and Cassin’s Auklet (#/3km²) during May-June 2004-2006. Krill patches are plotted as scaled NASC values and circle size indicates probable patch size of krill. Bathymetry starts at 200m with 100m increments.
Statistical analyses of bio-physical interactions (Schabenberger and Gotway 2005).
As a first test of correlation between physical and biological data matrices we will use Mantel tests. The test simply explores the significance of correlation between the spatial patterns of the data matrices. This will be performed on sea surface temperature and color data, biological series, and relationships to fronts. To evaluate spatial association (clustering) of physical and biological entities we will employ point pattern analysis and Moran's Index. We will then extend these descriptive statistics into a predictive framework to determine the capacity to model the effect of environment on specific spatial patterns of biological responses. This will be accomplished by spatial autoregressive models. Similar to time series analysis, spatial autoregressive models will use neighboring values to correct for spatial correlations and then allow for regressing a dependent variable (biological response) to an independent data matrix (environmental forcer). With these analyses we will build predictive models of prey and predator distribution and foraging from which we can evaluate the effects of oceanography on distribution and production of populations and the community. We will then apply georeferenced productivity models to salmon abundance estimates. For instance, it is likely that seabird behavior will inform us about the links between seabird-salmon correlations.

(4) Apply these results to salmon assessment and management
The results of Wells et al. (2008) and the extension of those results shown in Figure 1 make it clear that the benefit of including ecosystem information into decision support of Central Valley Chinook salmon is critical for better management of the population. Here, we propose to quantify relationships between salmon dynamics and mesoscale and temporal variability in oceanography and production between and within years across a region demonstrated to be important to the dynamics of Central Valley salmon. When completed we will go beyond correlative relationships between trophic levels and the environment of the region and, instead, will have developed mechanistic models (e.g., the impact of advection across the ecosystem) that will allow for precise forecasting of salmon abundance and likely distribution in the region. Ultimately, once we have quantified the relationships between remotely-sensed environmental data and production of the ecosystem (from primary production to top predators) we can use remotely-sensed environmental data within and across salmon run seasons to derive timely estimates of stock abundance from regressive approaches, likely distribution (e.g., Heike et al. 2005a, b), and the overlap of distribution and highly productive regions (using geostatistics). We can provide tools to alter, or redirect fishing efforts, to best protect the salmon in the region, identify essential habitats (those demonstrating an overlap between salmon distribution and high production), identify the factors related to variability in essential habitats, and adapt management in a timely fashion. Ultimately the results will allow for more informed management decisions and protection of a valuable resource.

Benefits to NASA and Society
In this project, we will address goals of the NASA's Earth Science Research Program in that we study planet earth from space to advance scientific understanding and meet societal needs. Specifically, we address a critical study interest of the NASA Research Announcement Research Opportunities in Space and Earth Sciences: Healthy marine ecosystems rely on a diversity of biological, chemical, and physical processes that function at different scales. Moreover, results from this work directly apply to spatially-informed management and conservation of natural resources and demonstrate the utility of global imaging for understanding local population,
community, an ecosystem dynamics. Therefore, we will serve a direct product to NOAA Fisheries, the PFMC, and other NOAA programs (e.g., National Marine Sanctuaries).

Peer reviewed products from this work will include: 1) bio-physical models for krill and rockfish along central California, 2) biophysical models for prey and seabird interactions, and community dynamics, 3) the influence of spatial heterogeneity in oceanographic features and prey distribution on seabird productivity, and 4) development of a seabird index of ecosystem state and prey abundance, 5) develop improved salmon management models. The final corollary to this effort will be an improved understanding of the ecosystem that the salmon live in, from basic oceanography to primary and secondary production to forage fish and their predators.

**Project management**

Francisco Chavez is Principal Investigator and will be responsible for preparing annual reports and overall management of the project. On a day-to-day basis he will manage the remote sensing and modeling aspects of the proposal. Co-Is Chai, Chao, Foley and Bograd will work with Chavez on this aspect. Brian Wells is the Institutional PI for NMFS and in charge of management of the development of the salmon indices. Co-Is Danner, Ralston, Field, Lindley, Santora, and Sydeman will work with Wells on this aspect of the project. Brian Wells is an ecologist and biological oceanographer with University of California, Santa Cruz (UCSC) and NOAA Fisheries. His previous work on the central coast ecosystem (Figures 1 and 2) demonstrate his familiarity with the system and system components as well as a working knowledge of novel methods for presentation and understanding of the biological oceanography. Stephen Ralston has thirty years of experience in the study of rockfish dynamics and oceanography, and is the chief scientist in charge of sample collection, personnel, and future direction. His presence on this grant secures our use of trawl data and future collections. John Field has published extensively in the field of ecosystem ecology, stock assessment methods and fisheries management. His current position is as a research fishery biologist, and he has also been involved in the research cruise for the past five years. It is his work that will be extended in the study of shortbelly rockfish. Eric Danner is contracted with NOAA as the lead GIS specialist in landscape ecology and will consolidate and present spatial data in a usable format. Also, Eric Danner will be involved in the spatial statistical analyses. William Sydeman is lead of the Farallon Institute and is well published in seabird biology and dynamics in the central California region. He is considered lead in his field for bringing seabirds online as ecological indicators of ecosystem state. His presence on the grant assures access and understanding of at-sea seabird data resources. Jarrod Santora is with the Farallon Institute and has expertise in quantified interpretation of acoustics data and is currently determining krill abundance and distribution in the central California region. Steve Lindley has served on various salmon assessment groups for PSMFC and acts as a liaison between our science and its application to decision support. Bill Peterson is a collaborator that acts in an advisory capacity for both groups.

Specific tasks are as follows:

**Year 1** – Analyze retrospective and forecast model simulations (Chavez)

**Year 1** – Develop and test salmon indices (Wells)

**Year 2** – Provide experimental forecasts to user, learn lessons, improve products (Group)

**Year 3** – Provide operational system to user, learn lessons, improve products (Group)
Close collaborations will be kept with NASA-funded salmon proposal for Pacific Northwest. Bill Peterson will serve as the main conduit and we expect participation of both groups in annual meetings and in particular during an external review proposed for this project mid-year during Year 2. We will also involve ERD heavily in the process since we expect that they will be the operational element and continue to provide the decision support tools developed as part of this proposal to managers.

**ROSES Improving Decision Support System for central California salmon (Chavez)**

**Earth System Models**
- National Center for Environmental Prediction (NCEP)
- Regional Ocean Modeling System (ROMS)
- Pacific Basin Circulation at 12 km
- Carbon, S(Or)F, Nitrogen
- Ecosystem (CoSINE)
- NPZ ecosystem model
- Individual Based Model (iBM) for Salmon

**Predictions/Forecasts**
- Specific products or types of predictions from the models
- Specific interoperability, data fusion, and other information technology to support integration

**Decision Support Systems, Assessments, Management Actions**
- Decision support system targeted at Fisheries Management Plan (FMP) for Pacific Coast Salmon
- Implemented by Pacific Fishery Management Council
- Specific analyses to support the decision making

**Value & Benefits to Society**
- Improved estimates of current and forecast ocean salmon abundance and determination of essential fish marine habitats, between and within fishing years
- Specific Decisions / Actions
  1. Adjust salmon harvest to appropriate levels, or in extreme cases close/open fishery
  2. ESA listing/delisting of species
  3. Protection within critical habitats

**Figure 8. Decision support system for central California salmon.**
References


Biosketch
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Voice: 831-775-1709, FAX: 831-775-1620, Email: chfr@mbari.org

Professional Preparation:
Humboldt State University  Oceanography     B.S., 1977
Duke University     Botany     Ph.D., 1987

Appointments:
2000-present  Senior Scientist, MBARI
2000-present  Faculty (courtesy), Stanford University
1996-2000  Associate Scientist (III), MBARI
1992-1996  Associate Scientist (II), MBARI
1990-present  Research Associate, University of California, Santa Cruz
1987-1992  Assistant Scientist, MBARI

5 Most Relevant Publications

5 Additional Publications

**Synergistic Activities:**
Served on a number of ORION/OOI and IOOS committees
Moved MBARI development to moorings of the TAO array

**Collaborators:**
Fei Chai (University of Maine), Niki Gruber (UCLA), Richard Dugdale (SFSU), Don Croll (UC Santa Cruz), Adina Paytan (Stanford), Dennis Hansell (University of Miami), Curt Collins (NPS), Ken Johnson (MBARI).

**Graduate Advisor:**
Richard T. Barber

**Committee Member of Following Graduate Students:**
Rafael A. Olivieri (UCSC), M. Celia Villac (Texas A&M), Jonathan Phinney (UCSC), Elena Mauri (MLML), Amy Little (UCSC)

**Post-Doctoral Advisor for:**
Chris Scholin, Raphael Kudela, Peter Strutton, Russell Hopcroft, John Ryan, Carmen Gonzales Castro, Brad Penta, Victor Kuwahara, Kevin Mahoney, Lionel Pawlowski, David Field

**Professional Societies:**
American Association for the Advancement of Science
American Geophysical Union
American Society of Limnology and Oceanography

**Selected Professional Activities and Honors**
National Science Foundation (NSF) Alan Waterman award committee (2003-2005)
Advisory Committee for Instituto del Mar del Peru (2004-)
Board of Directors, Center for Integrated Marine Technologies (2002-)
Board of Governors, Pacific Coastal Ocean Observing System (2004-)
Governing Council (Vice-President) Central and Northern California Ocean Observing System (2005-)
Steering committee for OceanSites (2004-)
Fellow of American Association for the Advancement of the Sciences. (2005) Honored for distinguished research on the impact of climate variability on oceanic ecosystems and global carbon cycling.
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EDUCATION

December 2000 Ph.D. Ecological Sciences - Old Dominion University, Norfolk VA, 23529
Dissertation: *Evaluation of fish scale chemistry for determining habitat associations.*

August 1994 M.S. Biological Sciences - Old Dominion University, Norfolk, VA, 23529.
Thesis: *The reproductive biology of Chesapeake Bay black drum, Pogonias cromis, with an assessment of fixatives and stains for histological examination of teleost ovaries.*

August 1991 B.S. Forestry and Wildlife, Fisheries Science – Virginia Polytechnic Institute and State University (VPI&SU), Blacksburg, VA, 24061.

PROFESSIONAL EXPERIENCE

April 2003 - Present: Research Associate, University of California Santa Cruz (UCSC) and National Oceanic and Atmospheric Administration Fisheries, Santa Cruz

April 2002 - Present: Adjunct Assistant Professor, Department of Natural Resources Conservation, University of Massachusetts, Amherst

April 2002-April 2003: National Research Council Research Associate, NOAA Northeast Fisheries Science Center, Cooperative Marine Education and Research Program, University of Massachusetts, Amherst

January 2002 - April 2002: Research Scientist – Old Dominion University


PEER-REVIEWED PUBLICATIONS


1 Alternate mailing address: NMFS Southwest Fisheries Science Center, Santa Cruz Laboratory, 110 Shaffer Road, Santa Cruz, CA 95060
Relationships between oceanic conditions and growth of Chinook salmon (*Oncorhynchus tshawytscha*) from Alaska, Washington, and California, USA. *Fisheries Oceanography.*


CURRICULUM VITAE

Fei Chai

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Present Positions:
Professor, School of Marine Sciences, University of Maine
Professor, Climate Change Institute, University of Maine
Adjunct Associate Professor, Nicholas School of the Environment, Duke University

Education:
B. S. 1984 Shandong College of Oceanology (Ocean University of China)
M. A. 1991 Princeton University (M. A. advisor: Prof. S. George Philander)
Ph.D. 1995 Duke University (Ph.D. advisor: Prof. Richard T. Barber)

Professional Experience:
2008 - Professor, School of Marine Sciences, University of Maine
2008 - Professor, Climate Change Institute, University of Maine
2002 - 2008 Associate Professor, School of Marine Sciences, University of Maine
2002 - 2008 Associate Professor, Climate Change Institute, UMaine
10/02 -3/03 Visiting Professor, Nagoya University, Japan
1996 - 2001 Assistant Professor, School of Marine Sciences, Univ. of Maine
5/99 - 8/99 Visiting Professor, Hong Kong University of Science & Technology
1994 - 1996 Research Assistant Professor, Department of Oceanography, UMaine

5 Most Relevant Publications


CURRICULUM VITAE

Yi Chao

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Education
Ph.D. 1988-1990, Atmospheric and Oceanic Science (AOS) Program, Princeton University
B.Sc. 1980-1985, Atmospheric Physics, University of Science and Technology of China

Professional Experience
2006-present, Adjunct Professor, Department of Atmospheric and Oceanic Sciences, UCLA
2007-present, Manager, Climate, Ocean and Solid Earth Section, JPL
2006-2007, Deputy and Acting Manager, Earth Remote Sensing Science Section, JPL
2005-2006, Supervisor, Ocean-Atmosphere Interaction Group, JPL
1993-present, Scientist, Research Scientist, Principal Scientist, JPL
1990-1992, Post-doctoral Scholar, University of California at Los Angeles

Honors and Award
2005, Exceptional Achievement Medal, NASA.
1997, Best Paper Award, Supercomputing Conference 1997
1996, Lew Allen Award for Excellence, Jet Propulsion Laboratory.

Related Recent Publications
BIOGRAPHICAL SKETCH - William J. Sydeman
Farallon Institute for Advanced Ecosystem Research, PO Box 750756, Petaluma, CA 94975; wsysdeman@comcast.net, www.farallonsstitute.org - 707-478-1381 (mobile)

PROFESSIONAL PREPARATION:
M.Sc., Biology, Northern Arizona University, Flagstaff, AZ (1985).
B.S., Biology, Lewis and Clark College, Portland, OR. (1979)

APPOINTMENTS
6/2008 – present, Research Associate, Bodega Marine Laboratory, UC Davis.
8/2007 – present, President/Senior Scientist, Farallon Institute, Petaluma, CA
12/2000 – present, Research Associate, Integrative Oceanography, UCSD, La Jolla
10/1999 – present, Adjunct Professor, Biology, San Francisco State U., San Francisco.

PUBLICATIONS RELEVANT TO THE PROPOSED RESEARCH
Sydeman, W.J., and C. Grosch. Climate change, phase relationships and food-web controls in the upwelling-dominated central California Current ecosystem. Ecology (in prep.).

SYNERGISTIC ACTIVTIES WITH MANAGEMENT
03/08 – present, Science Advisory Team, California Ocean Protection Council
02/05 – 3/2007, Science Advisory Team, California Department of Fish and Game
10/03 – present, Co-Chair – Advisory Panel for Marine Birds and Mammals, PICES
5/03 – 6/04, Ecosystem Monitoring Working Group, CA National Marine Sanctuaries
1/03 – 6/04, Marine Reserves and Krill Harvesting Working Group, Monterey Bay NMS
1/99 – 1/01 - Squid Research Scientific Committee, California Department of Fish and Game

PH.D. ADVISORS: Jim Quinn, Louis Botsford, Alec MacCall, Susan Harrison, Alan Hastings

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Curriculum Vitae: Jarrod A. Santora
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EDUCATIONAL HISTORY

City University of New York-Graduate Center, New York, NY 2007
Major: Ecology, Evolution, and Behavior
Degree program: PhD Biology
Graduate Thesis: Foraging Ecology of Antarctic Seabirds in the Scotia Sea
Mentor: Dr. Richard R. Veit

City University of New York-College of Staten Island, NY 2000
Major: Biology
Degree attained: Bachelor of Science
Awards: Excellence in Biological Research
Research: Population Dynamics of the Semipalmated Sandpiper (*Calidris pusilla*) on Long Island

PUBLICATIONS

Santora JA, WZ Trivelpiece, and RR Veit. (in review: Auk) Simultaneous satellite-tracking and ship-based surveys of foraging Chinstrap Penguins (*Pygoscelis antarctica*).


Santora JA, CS Reis, RR Veit, AC Cossio. (in press) Interannual spatial variability of krill influences seabird foraging behavior near Elephant Island, Antarctica. Fisheries Oceanography


Santora JA, and RR, Veit. (MS to be submitted to Deep-Sea Research) Influence of a hydrographic front on krill and seabird aggregations, near Elephant Island, Antarctica.

Santora, JA, Dietrich, KD, Lombard, D. (submitted to CCAMLR) Fishing activity and seabird-vessel attendance near the northern Antarctic Peninsula. CCAMLR WG

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EDUCATION

B.A. Biology and Environmental Studies, University of California Santa Cruz, 1994.


PROFESSIONAL EXPERIENCE

2004-present  Research Fishery Biologist, Southwest Fisheries Science Center, NOAA
2003-2004  Postdoctoral Research Fellow, Institute of Marine Science, UCSC/NOAA
1999-2003  Research/Teaching Assistant, University of Washington
1998-1999  Knauss Sea Grant Fellow, House Resources Committee, Congressman G. Miller

HONORS AND AWARDS

Egtvedt Scholarship, University of Washington, 1999
Walter P. Jones Award for Excellence in Coastal and Marine Graduate Study, 1997
Thesis honors, UC Santa Cruz, 1994

SELECTED PUBLICATIONS


Curriculum Vitae for David G. Foley

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Education
M.S., Physics - University of California at Los Angeles, 1990
B.A., Mathematics and Physics - Cornell University, 1988

Experience:
2003 – present West Coast CoastWatch Coordinator, University of Hawaii and NOAA
Southwest Fisheries Science Center, Environmental Research Division
1996 - 2003 Central Pacific CoastWatch Coordinator, University of Hawaii and NOAA
Pacific Islands Fisheries Science Center.
1993 - 1995 Research Assistant, University of Southern California
1991 - 1993 Teaching Assistant, University of Southern California
1990 - 1991 Supervisor of Special Projects Group, Isotope Products Laboratory Inc.
1988 - 1990 Teaching Assistant, University of California at Los Angeles

Current Professional Activities:
Fellow – Cooperative Institute for Oceanographic Satellite Studies, Oregon State University
Member – User products Committee, Northwestern Association of Networked Ocean
Observing Systems (NANOOS)
Member – Data Management Committee, Central and Northern California Ocean Observing
System (CeNCOOS), 2004-present

Selected Recent Publications


CURRICULUM VITAE: ERIC M. DANNER

CURRENT POSITION
Ecologist, Fisheries Ecology Division, SWFSC, NOAA Fisheries, 110 Shaffer Rd, Santa Cruz, CA 95060, (831) 420-3917, eric.danner@noaa.gov

EDUCATION
Ph.D. Ecology and Evolutionary Biology, University of California Santa Cruz. 2006.
M.S. Marine Sciences, University of California Santa Cruz. 1998.
  Research focus: Intertidal Ecology, Community Ecology
B.S. Biological Sciences, California Polytechnic State University, San Luis Obispo. 1990.

EXPERIENCE
Sea Grant Trainee, UC Santa Cruz. 1995-1996.
Associate Scientist, RSI Services Corp. 1987-1991.

SELECTED PUBLICATIONS
Steven J. Bograd

NOAA, NMFS, Pacific Fisheries Environmental Laboratory
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RESEARCH INTERESTS: Physical oceanography; climate variability; upper-ocean processes; eastern boundary currents; physical-biological interactions; biologging.

CITIZENSHIP: U.S.A.

EDUCATION: Ph.D., Oceanography, 1998, University of British Columbia
M.S., Atmospheric Sciences, 1989, University of Washington
B.S., B.S., Physics, Atmospheric Sciences, 1985, University of Arizona

EMPLOYMENT: 2005-present Supervisory Research Oceanographer, NOAA NMFS PFEL
2007-present Research Associate, Integrative Oceanography Division, Scrippps Institution of Oceanography
2001-2005 Research Oceanographer, NOAA, NMFS, Pacific Fisheries Environmental Laboratory
2000-2001 Academic Administrator, Scripps Institution of Oceanography, University of California, San Diego
1998-2001 Post Graduate Researcher, Scripps Institution of Oceanography, University of California, San Diego
1993-98 Research Assistant, Department of Earth and Ocean Sciences, University of British Columbia
1989-93 Research Scientist, Joint Institute for Study of the Atmosphere and Ocean, University of Washington and NOAA/PMEL


HONORS/AWARDS: CalCOFI Postdoctoral Fellowship, Scrippps Institution of Oceanography, 1998; NOAA Southwest Fisheries Science Center, Employee of the Year, 2003; Dept. of Commerce Bronze Medal, 2007.

FIVE SELECTED PUBLICATIONS:
CURRICULUM VITAE: STEVEN T. LINDLEY

PRESENT POSITION:  Ecologist (team leader)

EDUCATION:  
- Ph.D., Biological Oceanography, Duke University, 1994.
- B.A. (with Honors and Distinction in the Major), Aquatic Biology, University of California at Santa Barbara, 1989.

EXPERIENCE:  
- 2005-present  Ecologist (team leader), Landscape Ecology Team
  Southwest Fisheries Science Center, NMFS, Santa Cruz, California
- 1996–2005 Ecologist, Southwest Fisheries Science Center, NMFS
  Santa Cruz / Tiburon, California
- 1995–1996  Research Associate, Duke University Marine Laboratory
  Beaufort, North Carolina
- 1994–1995 Postdoctoral Fellow, Stanford University

RESEARCH INTERESTS:  Landscape, ecosystem, community and population ecology of aquatic organisms, statistical and numerical modeling, time series analysis, stable isotopes, telemetry, mark-recapture.


SELECTED RECENT PUBLICATIONS:  
William T. Peterson  
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**Education**

1965  B.A. Biology and Chemistry, Pacific Lutheran University  
1969  M.S. Oceanography, University of Hawaii  
1980  Ph.D. Oceanography, Oregon State University

**Professional Experience:**

Oceanographer, NOAA/NMFS, Newport and Courtesy Professor, Oregon State University, 1995-present  

**Professional Activities:**

Editorial Board, J. Plankton Research; Contributing Editor, Marine Ecology Progress Series; Advisory Board, African J. of Marine Science; Chairman of the Steering Committee for the NOAA/FATE program (2005-2007); Member Board of Governors, Sir Alistair Hardy Foundation for Ocean Sciences, Plymouth England; Member, Climate Change and Carrying Capacity Program, PICES 2002-present; Organizing Committee for 3rd International Symposium on Zooplankton Production (Gijon Spain, May 2003); U.S.GLOBEC Scientific Steering Committee (1998-2001); NEP GLOBEC Executive Committee (2000-present); Co-Convenor,ICES/PICES/IOC Symposium on "Effects of climate change on the world oceans", Gijón, Spain, 2008. Member, Task Team to determine causes of collapse of Sacramento River Chinook Salmon, 2008.

**Five Recent Publications:**


**Outreach.** Peterson is regularly asked to speak on climate, ocean conditions and salmon. Past engagements include the Ocean Policy Advisory Committee, Mid-Coast Watershed Council, Oregon State Police/Fish and Game cops, Hatfield Science Center SeaFest, Quinault Indian Nation "Salmon and Eagle Festival", Oregon Coast Community College, Yaquina View Elementary School, Oregon State University Alumni/Life Long Learning Center, Capitol Manor Retirement Community, Northwest Power Planning Council, the Pacific States Marine Fish Commission, Pacific Fisheries Management Council and the Northwest Shellfish Growers Association. He was also featured in PBS Series, “Strange Days on Planet Earth”, and a KIRO-TV Seattle, Documentary on “Cold facts about global warming.
CURRICULUM VITAE: STEPHEN VAN DYKE RALSTON

Present Position: Supervisory Research Fishery Biologist, SWFSC, NOAA Fisheries, 110 Shaffer Rd, Santa Cruz, CA 95060, (831) 420-3949, Steve.Ralston@noaa.gov

Education (degree, major, school, year):
- B.A., Zoology, University of California, Los Angeles, 1971
- M.S., Zoology, University of Hawaii, Honolulu, 1975
- Ph.D., Fisheries, University of Washington, Seattle, 1981

Positions:
- 2000-present Supervisory Research Fishery Biologist, National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060
- 1988 - 2000 Research Fishery Biologist, National Marine Fisheries Service, 3150 Paradise Drive, Tiburon, CA 94920
- 1986 - 1988 Task Leader, Insular Stock-Assessment, National Marine Fisheries Service, Southwest Fisheries Center, 2570 Dole Street, Honolulu, HI 96822-2396
- 1982 - 1986 Fishery Biologist (Research), National Marine Fisheries Service, Southwest Fisheries Center, 2570 Dole Street Honolulu, HI 96822-2396
- 1978 - 1981 Associate Investigator, University of Hawaii Sea Grant Program, Honolulu, HI 96822

Professional Affiliations:
- American Fisheries Society – Early Life History & Marine Sections

Professional Appointments:
- Adjunct Professor of Biology – February 1990, Department of Biology, San Francisco State University, San Francisco, CA
- Research Associate – July 2000, Institute of Marine Sciences, University of California

Service on Scientific/Technical Committees:
- Scientific and Statistical Committee (vice-chairman), Pacific Fishery Management Council (1999-present)

Scientific/Technical Specialties: Fisheries Population Dynamics, Stock Assessment, Age & Growth of Fishes, Recruitment Processes, Fishery Oceanography, Marine Protected Areas, Groundfish Management

Selected Recent Publications: