Sydeman (Farallon Institute): Baseline Monitoring of Ecosystem and Socioeconomic Indicators for MPAs along the North Central Coast of California: Integrated Ecosystem Assessment (IEA) and

Goals and Objectives

California's North-Central Coast (NCC) MPAs are being established during a period of substantial climate variability and change (e.g., Di Lorenzo et al. 2008, Rykaczewski and Checkley 2008, Bograd et al. 2009). Recognizing ongoing change in various climatological and ecosystem components, the Monitoring Enterprise has requested an assessment of ecosystem conditions of the region. An appreciation of ecosystem status and trends leading and during the initial stages of MPA implementation will promote better understanding of the baseline monitoring results. Indeed, given recent climatological variation, evaluating climate-ecosystem variability may be essential to reveal and attribute changes in MPAs to a reduction in fishing effort. In this section, we address the need to provide the ME with a regional integrated ecosystem assessment (IEA) during the initial baseline monitoring activities.

Methodology

Developing an IEA is a task of integration, and includes both physical and biological variables obtained on the appropriate spatial and temporal scales of interest. To accomplish this task, we will develop and report upon a series of integrated *multivariate indicators* of (a) "ocean climate", and (b) biological populations and productivity, which together will serve to characterize the state of the regional ecosystem. We define the region of interest as coastal continental shelf habitats from Half Moon Bay to Point Arena, California. Fortuitously, there is a wealth of physical and biological oceanographic data, which when examined and coupled, as possible, with baseline monitoring results, will provide an informative IEA. Many of these data have been compiled in various databases; one of these is entitled the *Integrated Marine Ecological Database* (**IMED**; Farallon Inst., unpubl.), developed, in part, to support ongoing NOAA/Integrated Ocean Observing System (IOOS) efforts to understand short- and long-term climate-ecosystem variability. The **IMED** contains ~200 time series of inter-related meteorological, climatic, oceanographic, and biological time-series datasets in the NNC. We will augment the **IMED** with new data collected during the baseline monitoring efforts which will provide information on all NCC habitats. This will include information on benthic fish and invertebrate abundance from submersible, diver, and collaborative fisheries research projects, and other biological information from sandy beach and rocky intertidal habitat surveys. We will synthesize and harmonize these data using statistical techniques such as empirical orthogonal function (EOF) analysis which allows for simultaneous investigation of multiple scales of temporal and spatial variability.

Outcomes and Deliverables

Initially, we will analyze each dataset for trends in "state" (mean or median values) and "variability" (variance) – this will provide <u>information on trends on climatological, oceanographic and biological variables at the time of MPA implementation</u> and during initial baseline monitoring efforts. Second, we will combine datasets using EOF to provide descriptive multivariate indicators of ecosystem status at implementation. This will provide an <u>integrated, holistic ecological perspective of the regional ecosystem</u>. Our approach will differ from other recent IEA efforts (Sydeman and Elliott 2008, Denny et al. 2008, Sydeman and Thompson 2009, Levin et al. 2009, Bograd and Sydeman 2009) in that we will focus on (a) a smaller (regional) scale (--- previous work has been on the scale of the entire California Current large marine ecosystem), (b) a suite of variables from habitats that have yet to be included in any other ecosystem status report, and (c) developing *interpretable* indices designed to meet specific needs of the MPA management community (Monitoring Enterprise, CDFG). Third, this module will serve to enhance collaboration and synergy between all project components. We will provide <u>an overarching ecosystem-level database template, inclusive of all project data and appropriate for use during future monitoring efforts</u>. Fourth, by conducting this integration and synthesis, we will provide a <u>regionally-based information infrastructure and, by virtue of the involvement of the PIs and their associates, a well defined network for information exchange focused on the NCC.</u> This information will be of considerable value to society for a variety of fisheries and marine ecosystem protection endeavors in the future.

INTEGRATED ECOSYSTEM ASSESSMENT AND MULTIVARIATE INDICATORS

Goals and Objectives

The North-Central Coast (NCC) Marine Protected Areas (MPA) are being established during a period of substantial temporal environmental variability and change. The impacts of climate change on marine ecosystems are not well known (Richardson and Poloczanska 2009), though clearly over the past 50 years ocean temperatures have increased considerably (Levitus et al. 2001). This trend is "highly likely" to continue for the foreseeable future (IPCC 2007). Indeed, the warmest global ocean temperatures on record were recorded in 2009 (NOAA, unpubl.). Therefore, there is critical need to assess climate-related ecosystem variability in addition to effects due to changes in fishing practices in order to comprehensively evaluate the efficacy of NCC MPAs during baseline and future monitoring.

There are predicted regional variations in marine climate change and ecosystem dynamics. In particular, upwelling-dominated ecosystems, such as the California Current, are expected to show significant regional variability in temperature, salinity, sea level, currents, ocean color, and other variables known to influence primary, secondary, and tertiary (fish and fisheries) productivity. As land masses are heating faster than the ocean, increased pressure gradients (ocean-based high pressure systems vs. land-based low pressure systems) may cause alongshore winds may intensify and lead to increased offshore Ekman transport and upwelling in these regions (Bakun 1990). Indeed, we understand the North-Central Coast (NCC) of California to be a region where upwelling intensification is already evident (Schwing and Mendelssohn 1997, Garcia-Reyes and Largier 2009). Ecosystem observations in the NCC have also been remarkable in recent years. In 2005, upwelling was delayed (a possible regional consequence of global warming; Schwing et al. 2006) and productivity reduced, with appreciable ecosystem consequences from plankton to rockfish to seabirds and marine mammals (Mackas et al. 2006, Brodeur et al. 2006, Sydeman et al. 2006, Wiese et al. 2006). In 2006, a similar "low-productivity" event was recorded. However, in 2007 and 2008, upwelling returned to near normal values, ocean temperatures dropped, and productivity improved. In 2009, upwelling was intense early in the season, but stopped, almost entirely in late May and June before increasing again in late summer. Nevertheless, biological productivity for many species was low. Indeed, the sequence of events, with interrupted or delayed upwelling in the NCC region in 2009 was reminiscent of the 2005 and 2006, both in terms of its physical driver(s) and biological consequences. Notably, in 2010 the NCC may be affected by an impending El Nino/Southern Oscillation event.

To date, a synthesis of these physical and biological changes in the NNC ecosystem has not been accomplished. Therefore, as part of our overall NCC MPA baseline monitoring project, we propose to integrate and describe trends and variation in physical and biological attributes of the regional ecosystem that have and are likely to affect the species and communities we will monitor in the NCC region. To make this investigation and report, we will design and develop an Integrated Ecosystem Assessment (IEA) for the region. The IEA will provide an evaluation of trends in physical and biological variables, in measures of central tendency (mean/median monthly or annual values) and variability (variance) leading to and during initial baseline monitoring, as well as a statistical analysis design to derive meaningful and interpretable "multivariate indicators" of (i) physical drivers and (ii) a variety of biological responses. In this manner, we will provide a report on ecosystem dynamics to the Monitoring Enterprise and MPA Management Community.

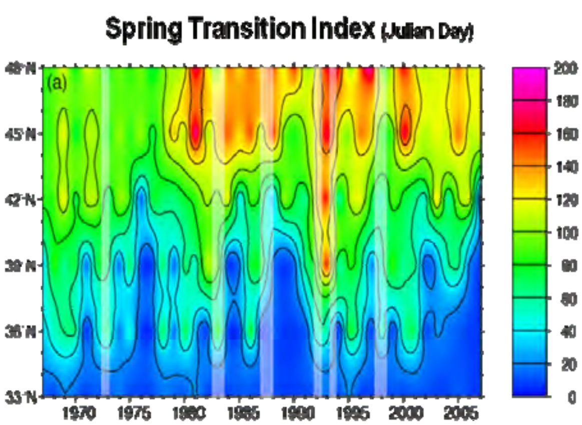
Methodology

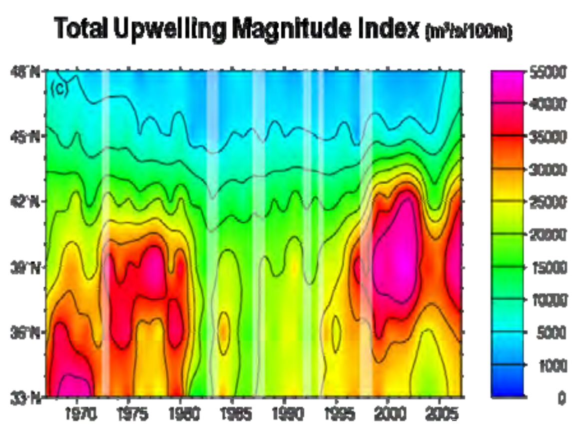
PARAMETER SELECTION

Despite its regional emphasis, the NCC is a large, dynamic and spatially heterogeneous marine environment. In addition to expected variability in *localized* upwelling, several other physical processes determine ecosystem structure, function, and services in the NCC. These include *basin-scale* effects exemplified by recent sub-arctic and sub-tropical water-mass intrusions (e.g. Bograd et al. 2003). From an oceanographic perspective, the NCC is under influence from the northeastern Pacific, as well as the tropical eastern North Pacific. Therefore, we will examine indices that provide a basis for understanding both local and basin-scale physical drivers of the NCC ecosystem. Much of the data needed for the project has already been compiled in databases by the proposers, including the California Current Integrated Ecological Database (Thompson and Sydeman, unpublished). Other key databases are available from NOAA-NMFS-Environmental Research Division (the ERD Data Access Portal), a project of NOAA's contribution to the Integrated Ocean Observing System (IOOS). In many cases, we will be updating time series, which makes this work possible for the funding levels requested.

Physical Forcing Variables

Upwelling. - To index localized upwelling in the NNC region, we will compile and report upon NOAA/NMFS Upwelling Indices (UI) from 36^{o}N (Monterey Bay) to 39^{o}N (Point Arena) (Bakun 1973, Schwing et al. 1996). Data from these locations will encompass the entire NNC MPA region, and provide specific information for coastal MPAs. The UI provides information on the offshore component of Ekman transport driven by geostrophic wind stress. Positive values indicate upwelling while negative values indicate downwelling. Data will be obtained from
http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling.
We will also derive other information from the UI, including an index to the spring transition, total length of the upwelling season, and magnitude of upwelling; an example is provided from Bograd et al. (2009).





Water Masses from the North. – We will use the North Pacific Gyre Oscillation Index (NPGOI) available from http://eros.eas.gatech.edu/npgo/data/NPGO.txt to assess water mass intrusions from the north (Di Lorenzo et al. 2008). Positive values indicate a strong North Pacific gyre and advective processes while negative values indicate a weak gyre and decreased advection. A related index will also be compiled and used to assess recent northeastern Pacific influence on the NCC. The Pacific Decadal Oscillation (PDO), developed by Mantua et. al. (1997), is derived from monthly sea surface temperatures in the entire North Pacific. Data are available from the Joint Institute for the Study of the Atmosphere and Ocean at the University of Washington, in cooperation with NOAA, at http://jisao.washington.edu/pdo/PDO.latest.

Water Masses from the South. – We will use the Multivariate ENSO Index (MEI), a combination of 7 observed variables over the tropical Pacific Ocean to provide an index to basin-scale influences to the south (Wolter and Timlin 1993). Negative values of the MEI represent the cold ENSO phase, a.k.a. La Niña, while positive MEI values represent the warm ENSO phase (El Niño). Data are available from http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html.

NCC Ecosystem Response Variables - Physical

Sea surface temperature (SST) and sea surface salinity (SSS) will be compiled from the Shore Stations Program of Scripps Institution of Oceanography. Methods and data are from http://shorestation.ucsd.edu/methods/index_methods.html. SST and SSS are available from a series of sites in the NCC region, some with time series extending back to 1919 (Hopkins), 1929 (Farallon Islands) and 1955 (Bodega Bay). We will compile all shore station data with time series > 30 years for this analysis. We will also compile and analyze SST data available from local NOAA buoys for the period 1980-present. These include buoy data from Point Arena, Bodega, San Francisco and Half Moon Bay.

Sea level measurements are available from the University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu/). We will use information from the sea level gauge at San Francisco.

NCC Ecosystem Response Variables – Biological

Lower Trophic Level Indicators. Satellite remotely-sensed chlorophyll concentration (mg m^{-3}, hereafter chl a) data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS; http://oceancolor.gsfc.nasa.gov/SeaWiFS/) are available in 9x9 km "blocks" from the NASA (http://oceancolor.gsfc.nasa.gov/). We have already processed and can therefore compile monthly composites for many MPA (combined SMR and SMCA) in the NNC region. The SeaWIFS data is of relatively short duration, 10 years (1998-2007), but will provide information on primary productivity leading up to MPA implementation.

Mesozooplankton (copepod and krill) bio-volume for the region is available from samples of taken by the California Cooperative Oceanic Fisheries Investigation (Brinton and Townsend 2003). Zooplankton is sampled with paired bongo nets, equipped with 0.505 mm mesh. Although initiated in 1949, the time series is missing many years and even decades. Methods and data are from http://www.calcofi.org/newhome/cruises/sample_analysis.htm. We will summarize information from Line 60, which traverses the shelf off Point Reyes for as many years as possible.

Mid and Upper Trophic Level Indicators***.***

Fish ***. -*** A very important dataset for MPA Baseline Monitoring is the NMFS Juvenile Rockfish Survey (JRS) which contains information on the abundance of age-0 pelagic juvenile rockfish (*Sebastes spp.*). Data are from mid-water trawls in May/June 1983-2009 in the NCC region. By rockfish species, an index of abundance (which reflects rockfish “reproductive success”) may be calculated. Data are available upon request from NMFS (S. Ralston and J. Field). We will use NMFS-derived indices for juvenile rockfish in our IEA. Moreover, juvenile rockfish have been sampled at specific stations in the vicinity of many NCC MPA. This specific data may, in time, provide information on “spillover” effects of protected *Sebastes* populations within SMR/SMCA. Last, the JRS provides a holistic perspective on the NCC region in its entirety. If the MPAs are functioning as a “network”, it may be possible to assess these larger-scale effects by looking at data from the NMFS JRS. This is something we will consider and discuss in further detail when developing and reporting this initial IEA for the NCC region.

Several indices of Chinook salmon abundance in the region are available from the Pacific Fishery Management Council (PFMC). The Central Valley Index (CVI) is a measure of the overall abundance that includes the ocean harvest south of Point Arena and the total escapement into the Central Valley. The CVI was not produced after 2007, but was replaced with a similar Sacramento Index. Because the two indices are highly correlated, we will use a dataset compiled of fall escapement values from the CVI from 1970-2007, and then the fall escapement value from the Sacramento Index for 2008. Information on Chinook Salmon escapement will also be obtained for the Russian River System from the Sonoma County Water Agency.

Seabirds. - The distribution and abundance of seabirds in the NCC region has been recorded on the NMFS Juvenile Rockfish Surveys since 1996 (W. Sydeman, unpublished data). We will develop and report upon the abundance (expressed as density) of 22 key species of seabirds in the region, including some dependent on the availability of juvenile rockfish as prey. Moreover, the reproductive success of seabirds has been studied at the Farallon Islands. Using published information and government reports we will summarize the annual reproductive performance of 6 species (murres, auklets(2), cormorants(2), guillemots) as an index to ecosystem productivity in the region. Seabird densities and reproductive performance are related to the abundance of juvenile rockfish in the system (e.g., Ainley et al. 1995, Sydeman et al. 2001, 2009), so the seabird data may also provide information on spillover, network, and larger-scale effects of MPA establishment in the NCC.

STATISTICAL ANALYSIS AND INTEGRATION

Univariate Trend Analysis. Most biological and geo-physical time series are serially auto-correlated (Ebisuzaki 1997, Pyper and Peterman 1998). Therefore, after compilation of time series datasets we will examine each for temporal autocorrelation. Next, we will examine each time series for trends. To test for trends we will use rank correlation, followed by linear and polynomial (quadratic) regression. The significance of temporal trends will be considered after adjusting for serial autocorrelation using techniques of Pyper and Peterman (1988).

Multivariate Analysis and Ecosystem Indicator Development. We will next employ multivariate time series techniques to (i) quantify the co-variance among different parameters and (ii) develop multivariate indices for inclusion in the NCC Integrated Ecosystem Assessment (IEA). One class of cross-correlation techniques is available for this kind of work is Empirical Orthogonal Function (EOF) analysis. EOF (a.k.a. PCA in the language of biologists) analysis is usually done with time series data from different spatial locations, as we have described herein. As an example, Mills et al. (2007) derived a “multivariate rockfish index (MRI)” using the NMFS JRS, seabird, and salmon food habits information in the NCC region. The eigenvectors of the co-variance matrix are the EOFs that describe the patterns of interrelationship among univariate indices. We will develop “physical” and “biological” indicators that reflect the state of the NCC ecosystem. The relative magnitude of these multivariate indicators (i.e., eigenvalues) are a measure of the "strength" of the relationships, i.e. the amount of variance explained by each eigenvector.

Notably, EOFs are "standing modes", in that they represent all interrelationships as being phase locked: that is, the relationships are either *in-phase (positively related)*, *time-lagged*, or *out-of-phase (negatively related)*. Consequently, we may also explore a more sophisticated tool, Complex EOF analysis, in which parameters are permitted to evolve temporally; as such, the amplitudes and phases of interrelationships are allowed to change through time, which is a more realistic approach to the dynamic NCC ecosystem. Notably, both EOF and COEF analysis techniques are based on the assumption that the time series are stationary, i.e. all moments are independent so that a time average is identical to an ensemble average. Therefore, assuming we will find trends, we will employ these analysis technique on de-trended time series (i.e,. residuals after the time trend is removed).

To make this information interpretable to the management community, environmental variables will be related to individual biological time series as well as to the leading eigenvectors extracted from combinations of physical and biological variables.

Deliverables and Societal Benefits of NCC Ecological Indicators

This information will be of significance to the MPA management community for improving understanding of change in biological populations within and outside MPA, and for fish and fisheries stock assessments in general. The report we will prepare, tentatively titled “An Integrated Ecosystem Assessment (IEA) for the North-Central Coast” will facilitate both immediate and long-term understanding of ecosystem dynamics and productivity leading up to and during baseline monitoring. This work has been designed to provide management with a toolbox to answer fundamental questions, such as: “are the biological changes observed during monitoring due to changes in management practices (e.g., a reduction in fishing effort) or changes in environmental and/or ocean conditions?”. The physical and biological indicators we will develop for this region will span multiple decades in some cases, thereby capturing long-term ranges of variability, and providing a robust context for interpreting future ecological change in the MPA management system.

Farallon Institute: Baseline Monitoring of Ecosystem and Socioeconomic Indicators for MPAs along the North Central Coast of California: Integrated Ecosystem Assessment (IEA) and Multivariate Indicators

<u>Workplan / Timeline</u>

-PI meeting, coordination, data/metadata standards discussion and coordination (1 March 2010 -1 Jan 2011)

-augment Integrated Marine Ecological Database with new data sets as well as update existing data sets (1 Jan 2011 – 1 June 2011)

-analyze data using statistical techniques such as empirical orthogonal function (EOF) analysis (1 June 2011 – 30 September 2011)

-report analysis results, draft report (1 October 2011 – 15 December 2011)

-provide framework and overarching database template (15 December 2011 – 25 February 2012)

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