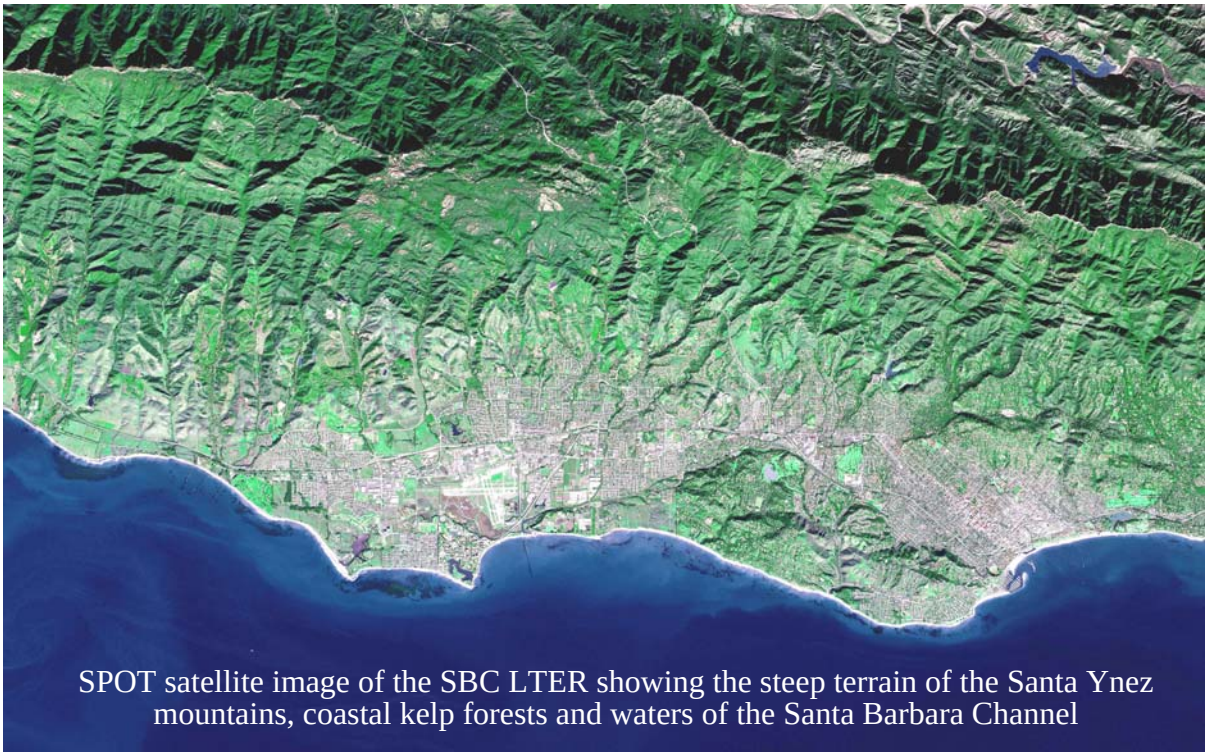
SANTA BARBARA COASTAL LONG TERM ECOLOGICAL RESEARCH PROGRAM



SPOT satellite image of the SBC LTER showing the steep terrain of the Santa Ynez mountains, coastal kelp forests and waters of the Santa Barbara Channel

MID TERM REVIEW DOCUMENT

PREPARED FOR THE NATIONAL SCIENCE FOUNDATION SITE REVIEW TEAM

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UNIVERSITY OF CALIFORNIA, SANTA BARBARA, CA

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I. SITE-BASED SCIENCE

Introduction

The Santa Barbara Coastal Long Term Ecological Research (SBC LTER) program (http://sbc.lternet.edu/index.html) was established in April 2000 and is housed at the University of California Santa Barbara. Its overarching objective is to understand the linkages among ecosystems at the land-ocean margin through interdisciplinary research, education and outreach with a focus on developing a predictive understanding of the structural and functional responses of giant kelp forest ecosystems to environmental forcing from the land and the sea. Giant kelp forests occur on shallow rocky reefs that fringe temperate coastlines throughout the world and are highly important to the ecology and economy of the regions in which they occur. Our principal study site is the semi-arid Santa Barbara coastal region, which includes steep watersheds, small estuaries, sandy beaches, and the neritic and pelagic waters of the Santa Barbara Channel and the habitats encompassed within it (e.g., giant kelp forests, deep ocean basins, pelagic waters and offshore islands).

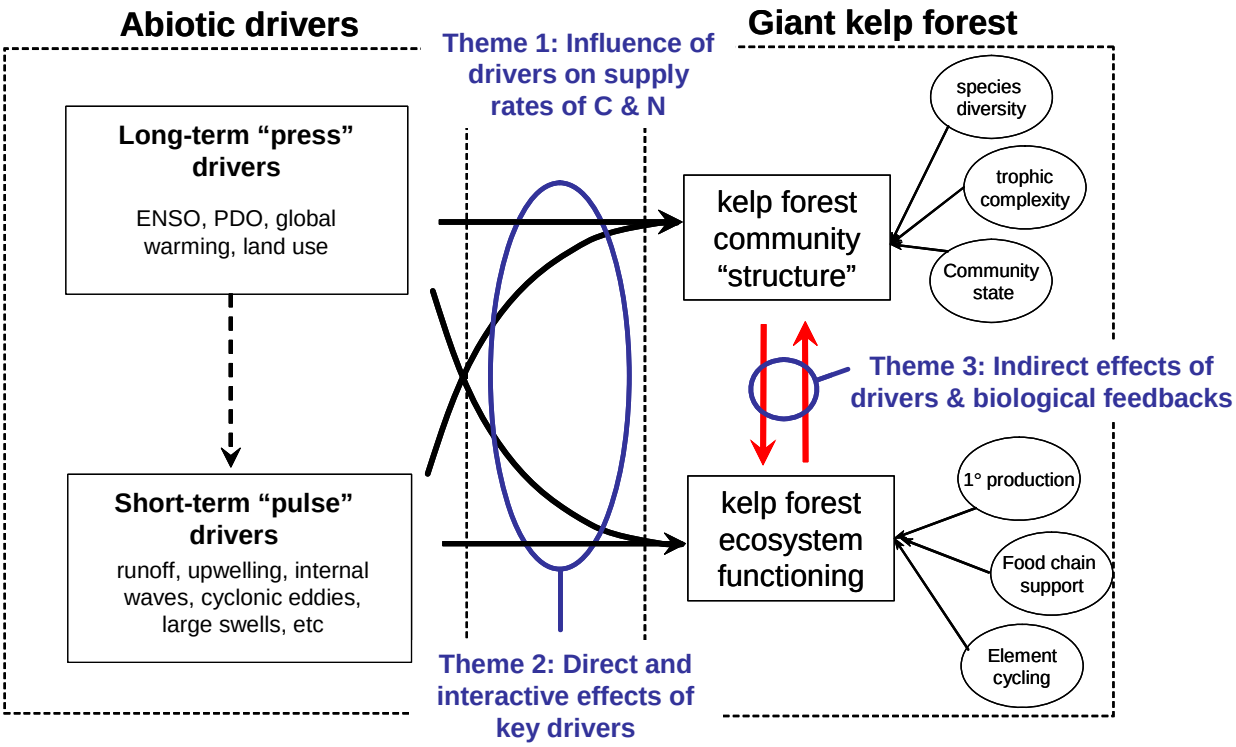
During our first six-year funding cycle our research focused on testing hypotheses and addressing questions relating to the role of terrestrial, oceanic and atmospheric forcing of observed dynamics in kelp forest structure and function. Much of this work centered on: (1) determining the dynamics of production and food web structure in kelp forests, (2) identifying the important processes on land and in the coastal ocean that drive changes in the nature and quantity of subsidies delivered to kelp forests, and (3) establishing sampling programs to generate long-term data sets that could address questions and hypotheses relating to the core areas of LTER research. This research led to substantial increases in our understanding of the study system. Armed with this increased knowledge we followed the advice from our first mid-term review and reduced our sampling effort in a number of these areas in order to more intensively pursue linkages among ocean, reef and land components and their propensity to change under different environmental conditions in our second cycle of funding.

Our ability to predict how coastal ecosystems will respond to environmental change requires a recognition that the drivers of change (e.g., climate, disease, human actions, and disturbances such as fires and ENSO events) typically act over different temporal and spatial scales. This inevitably results in a complex set of interactions among the biotic responses that these forcings elicit. The LTER Network has long been interested in environmental drivers that span a range of temporal and spatial scales and has recently formalized this interest into a pulse/press framework in which abiotic drivers act in a chronic long-term (i.e., "press") or periodic short-term (i.e., "pulse") fashion to influence biotic structure and ecosystem function (LTER Decadal Plan 2007). We adopted this framework for our current funding cycle with the goal of obtaining a more predictive understanding of the importance of land and ocean processes in determining the structure and function of giant kelp (*Macrocystis pyrifera)* forest ecosystems. The overarching question motivating our current research is:

> *How do abiotic drivers acting over different spatial and temporal scales influence kelp forest structure and function and its interactions with adjacent ecosystems?*

To address this question our research explores three general themes (Figure 1): (1) the influence of abiotic press and pulse drivers on exchange rates of N and C between giant kelp forests and adjacent land and ocean habitats, (2) the direct and interactive effects of key press and pulse drivers on kelp forest community structure and function through the modification of nutrient supply and wave disturbance, and (3) the indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between structure and function.

Figure 1. Conceptual framework of SBC LTER site research. Specific research questions and hypotheses are organized under one of three central themes (in blue). The solid black arrows represent the influx of physical disturbance and chemical subsidies as influenced by abiotic press and pulse drivers. The ecological consequences of interactions between press and pulse drivers (dashed arrow) are manifested over a time period that is greater than the current six-year funding cycle, which necessitates the need for long-term research.



THEME 1**:** The influence of abiotic press and pulse drivers on the rates of delivery of N and C to giant kelp forests

- *QUESTION 1a. How are the rates of delivery of N and organic C to giant kelp forests from terrestrial and oceanic environments altered by press and pulse drivers?*
- *QUESTION 1b. What are the sources and fate of dissolved and particulate organic matter in the nearshore zone?*

THEME 2: The direct and interactive effects of key press and pulse drivers on kelp forest community structure and function through the modification of nutrient supply and wave disturbance

- *QUESTION 2. How do wave disturbance and N loading act and interact to influence the structure, function, and resilience of the kelp forest ecosystem?*

THEME 3: Indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between them

- *QUESTION 3a. How do the negative effects of giant kelp on understory algae and phytoplankton interact with wave disturbance and N loading to affect the magnitude and interannual variability of NPP of the kelp forest ecosystem?*
- *QUESTION 3b. How does the kelp forest interact with its flow environment to modify the delivery of N and C and influence the species composition and performance of kelp forest biota?*

Short-term (hours to weeks) abiotic drivers that affect the delivery of nutrients and organic matter to kelp forests (e.g., upwelling, runoff) are embedded within a climatic regime (i.e., press driver) that fluctuates over much longer time scales (years, decades or more). The rate at which nutrients and organic matter are exchanged between kelp forests and adjacent habitats will depend not only on the direct effects of the pulse and press drivers, but also on the interactions among them (Theme 1, Figure 1). Abiotic drivers not only influence supply rates of N and C to kelp forests, but also the frequency and intensity of physical disturbance. Because the return interval of some of the key press drivers occurs on decadal and longer time scales, long-term research is needed to evaluate the ecological consequences of the direct and interactive effects of pulse and press drivers on the structure and function of giant kelp forests (Theme 2, Figure1). Like most natural systems, the structure and function of a giant kelp forest are inextricably linked. Thus, abiotic pulse and press drivers that directly affect the abundance and species composition of a kelp forest community will indirectly influence the system's capacity to fix carbon and take up nutrients used to support the complex kelp forest food web (Theme 3, Figure1). Similarly, the amount and form of organic matter produced by the kelp forest and made available to kelp forest consumers will in turn influence the abundance and species composition of organisms inhabiting the forest. Positive and negative feedbacks between kelp forest structure and function may arise from these indirect effects.

Site Characteristics

SBC LTER is ideally suited to explore issues of connectivity between terrestrial and marine ecosystems and the actions and interactions of pulse and press drivers on kelp forest structure and function. Our site is bounded by the Western Transverse Ranges of central and southern California to the north, the Channel Islands to the south, Pt. Conception to the west, and the Santa Clara River to the east (Figure 2). The catchments draining into the Santa Barbara Channel offer a rich diversity of watersheds that are characterized by a wide variety of land covers and uses. Giant kelp forms expansive forests on shallow rocky reefs, which dominate the nearshore in this region. Because of their close proximity to shore, kelp forests are influenced by physical and biological processes that occur on the land as well as in the open ocean (Figure 3). Streams and rivers transport nutrients, dissolved and particulate organic matter (DOM and POM), sediments, and pollutants from coastal watersheds to kelp forests, while ocean currents, internal waves, and other oceanographic processes supply nutrients, DOM, POM, larvae and plankton from adjacent offshore waters. In return, kelp forests export large amounts of DOM and POM to inshore intertidal habitats, as well as to offshore deep-water habitats. The transport of nitrate into the euphotic zone and disturbance from storm-generated waves are arguably the two most important factors regulating the standing crop and production of macroalgae (including giant kelp) in the coastal waters of southern California, and our research themes emphasize these two aspects. Short-term (i.e., pulse) and long-term (i.e., press) changes

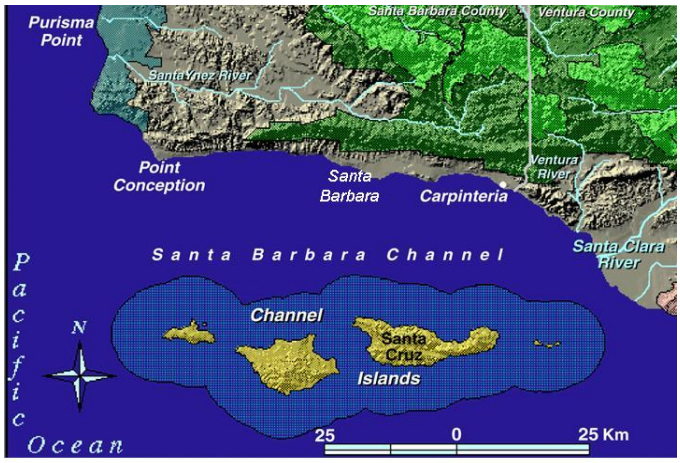


Figure 2. Regional map of SBC LTER. The site boundaries extend from Pt. Conception in the west to the Santa Clara River in the east, from the top of the Santa Ynez Mountains in the north out to the Channel Islands.

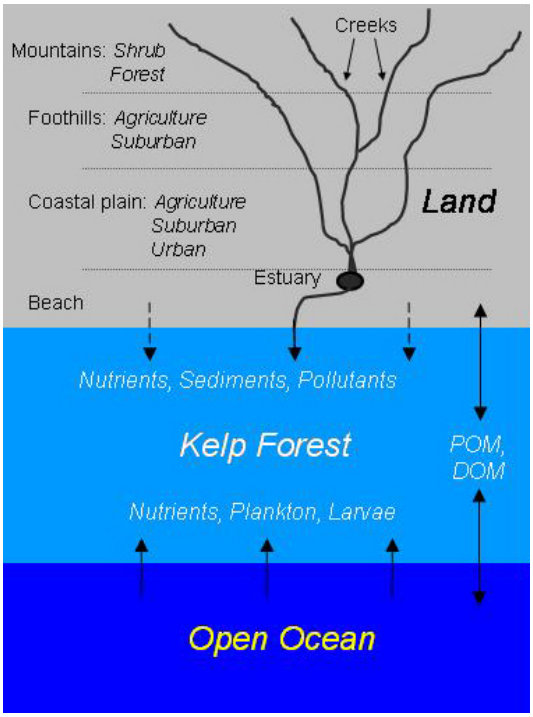


Figure 3. Material exchange between kelp forests and adjacent land and ocean ecosystems.

in climate, oceanography and land use or disturbances such as fire that directly or indirectly alter the disturbance regime and/or the supply of nutrients can have a profound influence on the structure of kelp forest communities and on the flow of materials to and from them.

The Santa Barbara region has a Mediterranean climate characterized by relatively calm, dry conditions in summer and autumn, prevailing NW winds in the spring, and episodic rain storms in the winter. This environmental setting creates strong seasonality in bottom-up forcing (via variation in the supply of nitrogen) and top-down control (via physical disturbance from storm generated waves). A number of "pulse" drivers operating on seasonal time scales influence these bottom-up and top-down forces including terrestrial runoff, large oceanic swells, wind-driven upwelling, internal waves, and other less understood oceanographic processes that supply nitrogen to otherwise depleted surface waters in summer and fall, and are thought to be important in enabling giant kelp to persist and grow year round in most years.

Aside from the seasonal cycle, the El Niño Southern Oscillation (ENSO) is the dominant climatic signal over most of the Pacific Ocean. The two phases of ENSO are generally termed El Niño (the warm, nutrient-poor phase) and La Niña (the cool nutrient-rich phase). The strengths of the various pulse drivers are El Niño dependent causing the relative contributions of land- and ocean-derived nitrogen and carbon to kelp forests in southern California to vary between El Niño and La Niña years, while the strength and intensity of El Niños vary with longer-term climatic cycles that have return frequencies of decades (e.g., the Pacific Decadal Oscillation).

General Research Approach

Certain abiotic drivers of kelp forest ecosystems are readily manipulated (e.g., physical disturbance that removes kelp), while others are difficult or practically impossible to manipulate on a meaningful scale (e.g., sea surface temperature, water column productivity, elevated runoff, land use change). Because of this, our research relies on a variety of approaches that include: (1) coordinated long-term measurements of key abiotic drivers and ecological response variables on land and intertidal beaches, in the offshore ocean, and in the shallow coastal zone to elucidate spatial and temporal patterns in the structure and function of giant kelp forests in the Santa Barbara Channel and in the physical and chemical forcing variables that influence them (Table 1), (2) manipulative field experiments designed to isolate the causal mechanisms underlying the patterns observed in long-term measurements, (3) measurement-intensive process studies aimed at obtaining a mechanistic understanding of processes that cannot be isolated using manipulative experiments, and (4) integrated synthesis using modeling and analyses that allow for predictions beyond the spatial and temporal scope of our data, and that help guide the direction of our future research. Collectively, these elements provide a powerful basis for building a greater understanding of the direct and indirect effects of

pulse and press drivers on kelp forest ecosystems, which is essential for predicting how giant kelp forests will respond to ongoing changes in the environment.

Table 1. Long-term core monitoring performed by Santa Barbara Coastal LTER (data available via the SBC LTER website http://sbc.lternet.edu/data/).

Title	Summary of measurements	Year initiated
Watershed Hydrology and Stream Chemistry		
Precipitation	Rainfall at 12 stations	2003
Stream Discharge	Stream stage and discharge at 9 stations (measurements were made at additional stations that are no longer sampled)	2002
Stream Chemistry	Storm-flow and base-flow sampling for nutrients and suspended matter at 8 stations	2001
Ocean Physics & Biogeochemistry		
Nearshore Ocean Water Chemistry Profiles	Profiled CTD and seawater nutrients, organic matter, & chlorophyll collected monthly at 5 reefs	2001
Moored Hydrography and Currents	Near continuous measurements of conductivity, temperature, & currents (ADCP) at 4 reefs	2001
Temperatures	Bottom temperature every 15 min at 11 reefs	2001
Irradiance	Bottom and surface irradiance every min at 4 reefs	
Kelp Forest Ecology		
Kelp forest Community Structure	Annual data on the abundance (density or % cover), species composition and size structure of fishes, macroinvertebrates, giant kelp and understory algae at 11 reef sites	2000
Long-term Kelp Removal Experiment	Twice per season sampling (every 6 weeks) in kelp-removal and kelp-control plots at 4 reef sites. Sampled variables include: the abundance, species composition and size structure of fish, macroinvertebrates, and macroalgae, standing and detrital biomass of macroalgae	2008
Kelp Net Primary Production	Monthly data on standing biomass, stoichiometry and biomass loss rates of giant kelp; seasonal data on giant kelp NPP	2002
Sandy Beach Ecology		
Macroalgal Wrack	Composition, cover and biomass of macroalgal wrack at 5 beaches	2008
Shorebirds	Shorebird density and species composition at 5 beaches	2008

*Other long-term data available from third parties include meteorology, ocean swell height and period, surface currents, satellite imagery (color, SST, kelp cover), rainfall, and stream discharge.

Research Summaries of Programmatic Areas

Below we summarize our major research activities in the three general thematic areas upon which our current award is structured. We note that much additional research not reported below has been and continues to be done with support from the Santa Barbara Coastal LTER. A full list of SBC LTER's publications can be found at: http://sbc.lternet.edu/catalog/publications.jsp.

THEME 1: The influence of abiotic press and pulse drivers on rates of delivery of N and C to giant kelp forests

Oceanic transport of offshore shelf C and N to the inner shelf

To understand the effects of the important abiotic processes of ocean circulation and transport on the delivery of C and N to kelp forests, a broad range of oceanographic sampling has been conducted since the beginning of the SBC LTER. The main elements of the sampling are monthly small boat surveys, an array of moorings along the inner shelf in the Santa Barbara Channel, high frequency (HF) radars for measuring surface currents (Beckenbach and Washburn 2004), and a series of oceanographic cruises onboard UNOLS vessels during 2001-2006. Results from analysis of the oceanographic data bear directly on Questions 1a and 1b of Theme 1.

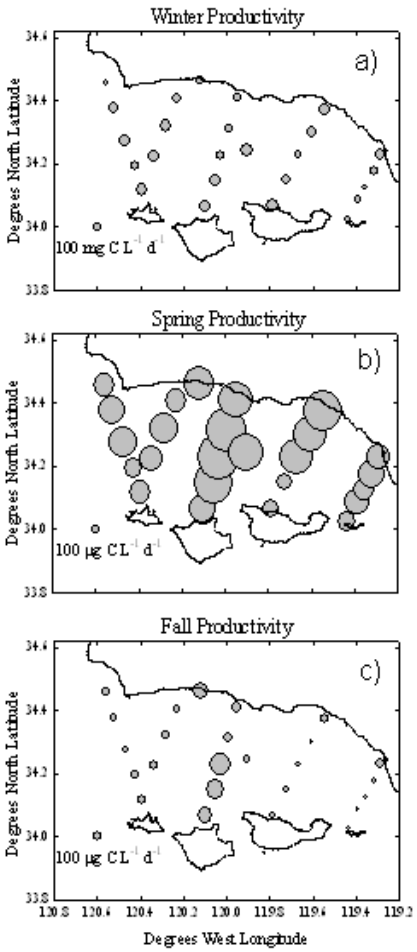


Figure 4. Phytoplankton primary productivity averaged by season. Dot size indicates productivity according to scale at lower left.

A major research focus during the first half of our current award has been the analysis and synthesis of the extensive data set from the oceanographic cruises. To date, our analyses of these cruise data have concentrated on issues related to Question 1b of Theme 1 by examining offshore oceanic sources of dissolved and particulate organic matter. In particular, we are studying the relationship between chlorophyll concentration and phytoplankton primary productivity (PPP) and the pulse drivers of wind-driven upwelling, seasonal river runoff, eddy circulation, and water mass variability. Satellite remote sensing imagery (e.g., Otero and Siegel 2004) suggests that two areas of the Santa Barbara Channel have consistently high levels of chlorophyll, the western channel and the eastern channel along the mainland coast near the mouths of the Ventura and Santa Clara Rivers. Prevailing coastal circulation patterns place these regions of high chlorophyll upstream from extensive kelp forests along the mainland coast because: (a) offshore currents are counter-clockwise and tend to transport materials from the western channel toward the mainland shore in the central portion of the channel, and (b) nearshore currents along the mainland coast are predominantly westward. Therefore we hypothesize that these areas are important sources of organic particles for kelp forests along the mainland coast where core SBC-LTER monitoring sites are located. An important goal of our cruise analyses has been to quantify patterns of PPP and chlorophyll measured *in situ* with patterns inferred from remote sensing.

Patterns of PPP during 15 UNOLS cruises show a seasonal cycle in the Santa Barbara Channel with high productivity in spring and lower productivity in fall and winter (Figure 4). The first empirical orthogonal function (EOF) mode derived from the PPP measurements was nearly spatially uniform and accounted for 67% of total variance. Correlation of this mode with nitrate concentrations indicates it describes wind-driven upwelling effects. The second EOF mode accounting for 17% of variance exhibited a productivity maximum in the western channel centered over the deep Santa Barbara Basin. The signature of this mode is evident along the central transect line during spring and fall (Figures 4b and 4c). Comparison with current patterns observed by shipboard current profilers and shore-based HF radar indicates this mode is large when organized cyclonic circulation prevails in the western channel and small when it does not. It also is consistent with previous remote sensing observations of a chlorophyll maximum in the western portion of the channel. We are currently exploring which aspects of the cyclonic circulation enhance PPP; two leading contenders are increased residence time and local supply of nutrients by uplift of density surfaces.

Analysis of our UNOLS cruise data during the second half of our current award will continue to focus on Theme 1 as we will examine ocean transport processes that deliver N and C from the regions of high PPP identified in our current analysis to nearshore kelp forests. This research will involve all SBC LTER oceanographic data sets including the UNOLS cruises, monthly observations from the Plumes and Blooms program (see below), and nearshore monthly water sampling and moorings. Another direction that we are planning is a study of the effects of El Niño. As of this writing an El Niño is developing in the western Pacific which, if it continues to build, will give us the opportunity to measure its effects throughout the SBC LTER study area, including the coastal ocean. In preparation, we are discussing with NSF program managers and ship operations personnel the possibility of an oceanographic cruise for late summer or fall 2010. A third research direction that we are planning involves near continuous oceanographic sampling using the new technology of gliders. We currently have NSF supplemental funding to purchase one glider and are working on proposals (e.g., NOAA and NASA) to purchase a second and to fund the required technical support personnel. Data from gliders will allow near continuous observation of evolving ocean conditions that will enhance our previous research on the formation of toxic algal blooms (Anderson et al.. 2006, 2008, 2009, Sekula-Wood et al. 2009) and coastal eddies (Bassin et al. 2005) as well as facilitate our future planned research on effects of storm driven runoff. Partnerships are also being explored to understand consequences of newly identified press drivers such as ocean acidification and declining oxygen levels in the northeastern Pacific. Some of this work has already begun. For example, measurements of the coastal ocean bicarbonate system have been added to the monthly cross-channel sampling of co-PI Siegel's long-term NASA-funded Plumes and Blooms project (in collaboration with Wei-Jun Cai of the University of Georgia), and we will be obtaining the equipment required to implement these measurements at our long-term monitoring sites with NSF supplemental funding.

Inner shelf transport and the sources and fates of DOM

The exchange of materials between kelp forests and the deeper ocean is governed by processes that transport materials across the continental shelf. The basin-scale cruise effort described above provides insight into biogeochemical processes that determine the quantity and composition of materials delivered from the outer continental shelf while the research described in this section focuses on exchange across the shelf and ultimately to and from giant kelp forests. Because the continental shelf in the Santa Barbara Channel is only a few kilometers wide in many areas, cross shelf processes have a large effect on the supply and export of key resources to and from the kelp forest ecosystem. The nutrients sequestered in organic matter (OM) are of particular interest because of their

ecological and biogeochemical significance. Organic matter (OM) is partitioned into particulate (POM) and dissolved (DOM) phases and is produced by photoautotrophic processes (phytoplankton and macroalgae). The portion partitioned into DOM serves as a substrate for heterotrophic microbial processes, and factors that control the production and remineralization of DOM can have a significant influence on the distribution of nutrients. We observed DOM concentrations in the center of the Santa Barbara Channel to be less than or equal to concentrations measured in the subtropical oligotrophic gyre at the same latitude, despite its proximity to the coast and relatively high levels of phytoplankton productivity. This relatively low background concentration of DOM allows us to resolve small changes in this important organic pool.

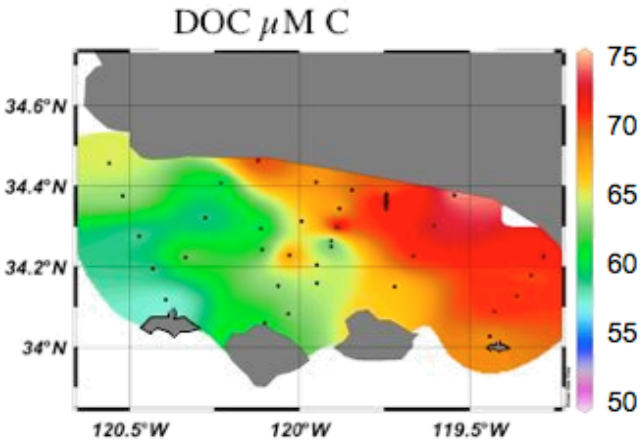


Figure 5. Surface contour of DOC in the Santa Barbara Channel in October 2005. Note DOC gradient that develops from onshore to offshore in the western portion of the SB Channel.

Our cross-shelf survey of the Santa Barbara Channel revealed a significant onshore to offshore gradient in the concentration of DOM indicating the build up of a pool of organic nutrients that could potentially be available for export away from the nearshore system (Figure 5). Knowledge of the sources and fate of the DOC produced in the nearshore is needed to gain insight into the bioavailability of this important organic pool. However, prior to our investigations little was known about the temporal evolution of this gradient, its persistence or how it developed in the context of primary productivity and potential availability to heterotrophic microbes.

In January 2008 we initiated a cross shelf time series to investigate the temporal and spatial gradients of particulate and dissolved organic matter and their potential sources and sinks in the nearshore environment. Monthly measurements of POM, DOM, nutrient concentrations, and the biomass, productivity and community structure of phytoplankton and bacterioplankton were collected for 16 consecutive months from 4 depths at 5 stations that spanned from the Mohawk kelp forest to 3 km offshore.

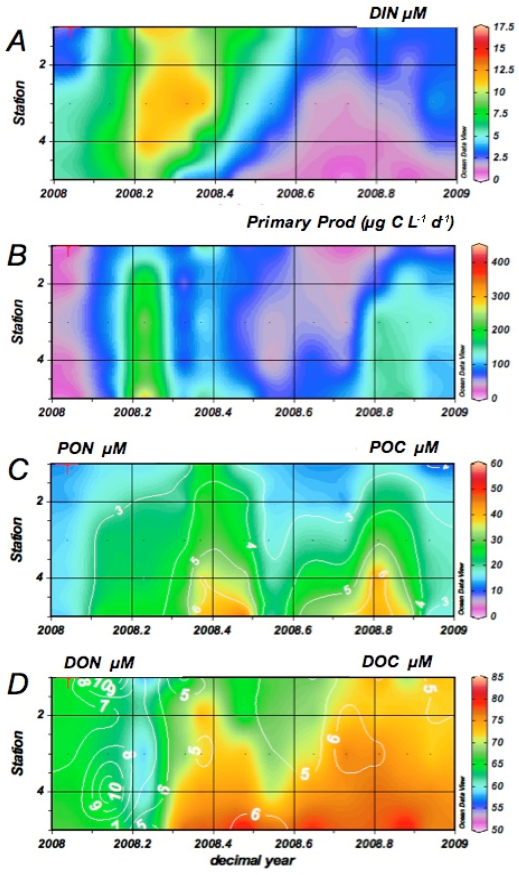


Figure 6. Surface contours of integrated and depth normalized measures of (A) inorganic nitrogen; (B) phytoplankton primary production; (C) POC and PON (overlay contour); (D) DOC and DON (overlay contour) collected during 2008 from the Mohawk kelp forest (station 5) to 3 km offshore (station 1).

Initial analysis of these data show significant temporal variability in cross shelf transport that results in the kelp forest ecosystem being largely isolated from offshore influences at some times and strongly influenced by offshore waters at other times. The horizontal transect from the Mohawk kelp forest illustrates seasonal gradients of organic and inorganic nutrients between the shallow rocky reef and deeper offshore ocean (Figure 6a). During periods of upwelling large pulses of inorganic nutrients were introduced into the nearshore and offshore environments (Figure 6a) resulting in a phytoplankton bloom in early spring across the 3 km transect (Figure 6b). As upwelling relaxed and inorganic nutrients were drawn down temporal gradients in POM and DOM developed, reaching maxima by late spring/early summer (Figure 6a, 6c, 6d). A pronounced spatial gradient in POM and DOM was observed with maxima developing closest to the kelp forest. In order for DOM and POM to accumulate in the nearshore zone, biological production and consumption processes must be uncoupled and the rate of physical dispersion must be less than net organic matter (OM) production. Thus, the accumulation of OM in the nearshore environment suggests that the connectivity between kelp forests and the offshore ocean is reduced during periods when upwelling is relaxed and kelp forests become relatively isolated from offshore waters. Additional microbial bioassays were also conducted throughout the study to assess the bioavailability of the accumulated DOM. Analyses of these data are ongoing and should provide further insight into the fate of the accumulated OM and its potential for export from the nearshore environment.

Watershed processes and land subsidies to kelp forests

Empirical studies: Seventy-four catchments, with a total area of 790 km^2 (ranging from 1 to 50 km^2), drain from the Santa Ynez Mountains along the northern coast of Santa Barbara Channel to coastal waters that support kelp forest ecosystems. These coastal catchments have mountainous headwaters and sloping coastal plains separated by transitional foothills. From west to east, there are both elevational and land use gradients. Headwater elevations increase from approximately 300 to 1400 m, and land uses on the coastal plain and foothills change from mostly rangeland to a combination of urban and agricultural land with chaparral in the mountains.

A network of rain gauges and water level recorders has been installed to permit calculation of rainfall and runoff for a representative set of coastal watersheds (Figure 7). Intensive sampling during rainfall events and weekly to bi-weekly collections during periods with baseflow are routinely performed in the instrumented watersheds. Water

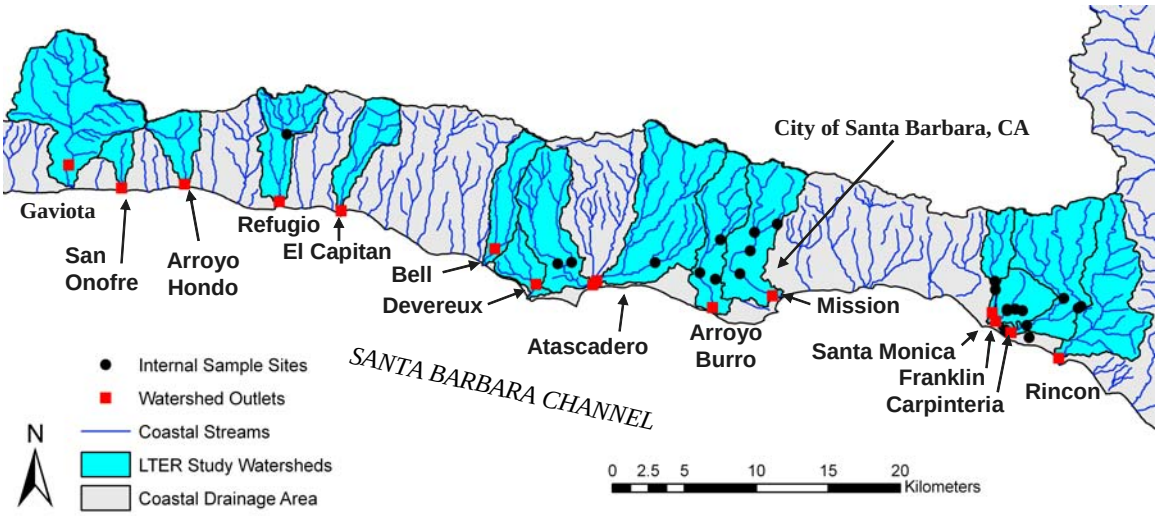


Figure 7. Catchments along the Santa Barbara Channel with LTER stream gauging and sampling stations (red squares indicate stations near mouth; black dots indicate stations within catchments).

samples from streams are analyzed for (a) nitrate, ammonium, total dissolved nitrogen, and particulate nitrogen; (b) soluble reactive phosphorus, total dissolved phosphorus and particulate phosphorus; (c) particulate organic carbon; (d) total suspended sediments; and (e) conductivity. Subsets of samples are analyzed for silica, major cations and anions, and the natural abundances of ^{15}N and ^{13}C.

Most of the annual precipitation and corresponding runoff occur in only a few large events resulting in high peak discharges and a rapid return to near baseflow conditions. Consequently, a major proportion of the annual fluxes occurs during a few large storms in each year. For example, in water year (WY) 2003, 46%, 28% and 40% of the respective nitrate, phosphate and dissolved organic nitrogen fluxes were exported during the largest event. We found that land use greatly affected nutrient export from coastal watersheds. Descending order of concentration and flux of nitrate and dissolved organic nitrogen usually followed descending intensity of land use. Volume-weighted mean concentrations of nitrate generally range from 5 to 25 µmol L^{-1} in undeveloped areas, increase to about 100 µmol L^{-1} for urban and most agricultural catchments, and are in excess of 1000 µmol L^{-1} in catchments with greenhouse-based agriculture. Comparative values for dissolved organic nitrogen are 10 to 25 µmol L^{-1} for undeveloped, 60 to 100 µmol L^{-1} for urban and agricultural, and about 200 µmol L^{-1} for greenhouse-based agriculture. Differences in phosphate concentrations were observed between intensive agriculture and urban or less intensive agricultural usage, and between urban and undeveloped catchments. To refine our whole catchment analyses we examined nutrient loading at the landscape-unit scale (Robinson et al. 2002, 2005a, 2005b, Robinson 2006). Two intensive agricultural land uses (greenhouses and nurseries) were, in general, higher than two urban classes (commercial and residential), which were higher than chaparral areas. Using an urban growth model to forecast land uses 50 years into the future and estimates of nutrient export for different land uses, we found that the forecasted reduction in agricultural land use and expansion of urban development leads to a decrease in nitrate export and an increase in phosphate export. Goodman (2008) includes export from the largely suburban catchment of Devereux Slough, which has the added complication that the slough is open to the ocean only occasionally.

The large variation in the concentration of nutrients in runoff during storms requires the sampling of nutrient export at a time step significantly less than one day (Melack and Leydecker 2005). For example, nitrate, soluble reactive phosphate and particulate organic nitrogen varied with the hydrograph: soluble reactive phosphate varied in phase with outflow, nitrate exhibited the opposite pattern, and particulate organic nitrogen concentrations, along with other particulates, reached a maximum on the rising limb of the first storm pulse,

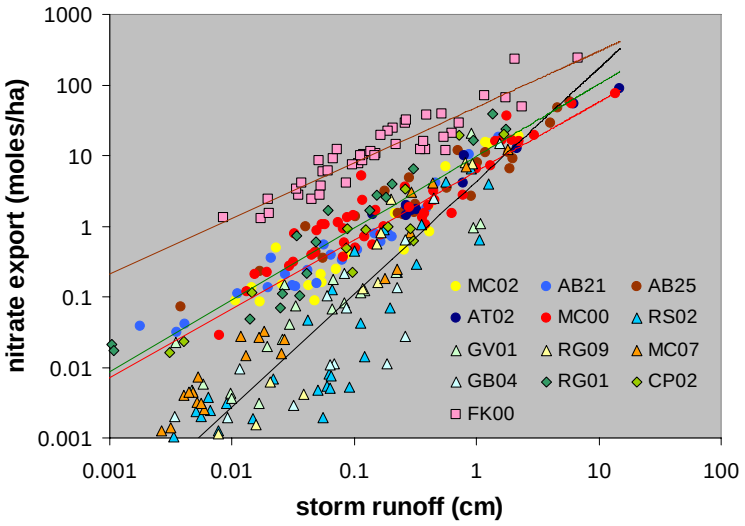


Figure 8. Nitrate exported per storm, expressed as moles ha^{-1}, and runoff per storm, expressed as cm per unit area, for the period from 2001 to 2005. Codes to creek names are as follows: MC, Mission; AB, Arroyo Burro; AT, Atascadero; RS, Rattlesnake; GV, Gaviota; RG, Refugio; CP, Carpinteria; FK, Franklin. Numbers after creek codes refer to position in catchment. Symbols indicate predominant land use in catchment as follows: ▲, undeveloped uplands; ●, suburban/urban; ◊, agriculture; ■, intensive agriculture.

implying different mechanisms and/or sources for the various species.

Figure 8 provides a synthesis of the relationship between nitrate exported per storm, expressed as moles ha^{-1}, and runoff per storm, expressed as cm per unit area, for the period from 2001 to 2005. Urban and agricultural land uses generate about the same export when agricultural use is10% or less. An especially interesting feature is the steep slope of nitrate export from undeveloped catchments. As long as storm size remains small, nitrate export from undeveloped areas is small (i.e., 10-100 times lower than from urban catchments). As storm size increases, there is a disproportional increase in export, and flux from these areas exceeds that contributed from urbanized or agricultural zones when storm runoff exceeds 2 to 5 cm per unit area.

To investigate the relative importance of marine and terrestrial sources of organic matter to the consumers in nearshore kelp reefs we measured stable isotopes of C and N in suspended organic matter and different types of consumers over a 4 year period in 4 nearshore areas with varying exposure to terrestrial runoff (Page et al. 2008). $\delta^{13}C$ values of suspended particulate organic matter on reefs tended to decrease following periods of significant rainfall at reefs most influenced by runoff. A pattern of ^{15}N-enrichment in 2 common benthic feeding species, the sea urchin *Strongylocentrotus purpuratus* and the annelid *Diopatra ornaata*, with increasing influence of runoff indicated that terrestrially-derived N may enter the food web indirectly through microbes or algae.

Fires impact the hydrology and suspended sediment and nutrient export. Stream gauging and intensive storm runoff and baseflow sampling were used to determine impacts from a fire that burned 3,011 ha in coastal watersheds near Gaviota bordering the Santa Barbara Channel in June 2004 (Coombs 2006). Burned watersheds showed order of magnitude increases in peak discharge, and suspended sediment export from burned watersheds was approximately 10 times greater than from unburned watersheds. Ammonium export from burned watersheds primarily occurred during the first 3 storms of the water year and was 32 times greater than in unburned upland watersheds. Nitrate, dissolved organic nitrogen, and phosphate export from burned watersheds increased by 5.5, 2.8, and 2.2 times, respectively, compared to unburned chaparral watersheds.

From July 2008 to June 2009, three major fires burned a large fraction of the foothills and mountains above the greater Santa Barbara area, all within the area being studied by the Santa Barbara Coastal LTER program. As the rainy season is approaching, we are planning to compare the influence of fire timing (autumn versus spring versus no fire) and fire severity on a variety of ecological and environmental responses. Measurements and modeling of stream discharge and the export of sediment and nutrients will be used to integrate watershed responses to fire and to link upslope disturbances, stream ecosystems, and nearshore marine environments. Soil movement and landslides will be measured at selected sites and synoptically with airborne LiDAR. Regrowth of vegetation will be determined at the watershed scale using high resolution remote sensing and at the transect scale by direct measurements of re-sprouting plants and ground cover. We will evaluate the production and consumption of NO_3^- in burned and unburned areas after the fires, before vegetation fully re-establishes, through measurements of nutrient concentrations and fluxes, measure N processing by microbes, and link N losses to hydrological processes. We have submitted a RAPID proposal to support these expanded studies.

Modeling studies: We have developed a hydrological model that predicts runoff from rainfall to extend our measurements of stream discharge and nutrients to all coastal watersheds entering the Santa Barbara Channel within our primary 790 km^2 study area (Beighley et al. 2003, 2005). Furthermore, we have used our rainfall-runoff model to explore the impacts of watershed characteristics, transient weather regimes and land conversion on the frequency distributions of runoff events and their influence on nearshore waters (Beighley et al. 2008). Based on historical evidence and projected urbanization, a 600% increase in runoff during storms from the coastal plain was calculated to occur from 1929 to 2050, which shifts the dominant source of runoff from

the mountains to the coastal plain. By combining drainage areas, export relationships, runoff frequencies, nearshore water volume, ambient nitrate and phosphate concentrations in nearshore waters and an assumed mixing volume, we modeled the probability of a runoff event resulting in a particular nearshore nitrate or phosphate concentration. For example, the frequency of a storm event that produces runoff $\geq$ 2.5 cm and a nearshore nitrate concentration greater than 12 μmol L^{-1} ranges from 3% in non-El Nino years to 20% in El Nino years.

Regression models have been developed to estimate the flux (mol ha^{-1}) for a given storm based on the percentage of catchment area used for agriculture or classified as impervious surface, the estimated discharge during the storm and the cumulative water year discharge at the end of the storm. Daily models were also developed to estimate the daily flux (mol ha^{-1} d^{-1}) using daily flow and the cumulative water year discharge at the end of the given day.

To extend our modeling to include mechanistic aspects of the water balance and N and C dynamics, we have begun to apply the Regional HydroEcological Simulation System (RHESSys). Initial work has focused on the effect of uncertainty in water and climate inputs on streamflow and evapotranspiration (ET) outputs in the Mission Creek catchment. We have tested model sensitivity to three sources of input uncertainty: spatial scaling of precipitation, non-linear variations in temperature caused by a marine fog layer, and outdoor water use. Results indicate that the model is most sensitive to uncertainty in soil parameters and precipitation inputs. Sensitivity to temperature variations resulting from a marine fog layer was negligible in terms of total water flux, but significant variations in ET and streamflow at the seasonal level were observed. Likewise, model sensitivity to outdoor water use was relatively small except potentially during the summer months. Future research in the Mission Creek catchment will be focused on quantifying the effect of fine scale urban spatial complexity and impervious surface connectivity on hydrologic and biogeochemical processes and appropriate modifications of RHESSys model will be developed. The model will then be used in conjunction with land use and climate change forecasts for the region with a goal of quantifying potential catchment responses to different environmental change scenarios.

C inputs to kelp forests identified by stable isotopes

Understanding trophic connections and how resource variability affects consumers is necessary to predict how food webs might shift in the face of environmental change. Research based on stable isotope analyses has supported the idea that macroalgal detritus, especially that of the giant kelp *Macrocystis,* is a major source of dietary carbon to benthic suspension-feeders. However, our recent findings from a four-year stable isotope study (Page et al. 2008) suggest that phytoplankton, not kelp, are the main food resource for benthic suspension-feeders on reefs in the Santa Barbara Channel, and that variation in phytoplankton abundance, combined with feeding selectivity and the scale of consumer tissue turnover times, may drive variability in consumer isotope values.

A common assumption made in 'snapshot' isotope studies of coastal ecosystems over the past 20 years is that the isotopic signature of coastal phytoplankton is similar to that of offshore phytoplankton. Our results suggest that this important supposition may be incorrect. Typically this assumption is made because of the difficulty in separating phytoplankton from detritus to obtain an uncontaminated isotope signature, also a problem encountered in freshwater systems. We are developing methods to overcome these problems and address fundamental questions about the role of POM in coastal food webs. Our objectives are to: (1) determine the contribution of phytoplankton and giant kelp detritus to the pool of suspended reef POM and whether POM composition varies with distance from kelp forests, and (2) evaluate how different components of the POM are used as food by reef suspension feeders. This work is being done using two complementary approaches: (1) an advanced flow cytometry and a cell-sorting system to

separate phytoplankton from bulk POM, and (2) analyses of essential polyunsaturated fatty acids (PUFA) in POM and consumers.

We have obtained preliminary data that demonstrate the feasibility of both of these methods (Figure 9), and have submitted an NSF proposal for support of expanded work on these issues. Isotope values of isolated inshore phytoplankton and kelp, and compound-specific PUFA, will be used in mixing models to estimate relative contributions of these two major primary producers to suspension feeder diets. They will also test two hypothesized mechanisms influencing isotopic composition of consumers: (1) selective feeding on particular fractions of the POM, and (2) tissue turnover times.

Results from this work should provide new insights into the trophic support of benthic suspension feeders, an ecologically and economically important guild in coastal ecosystems. This research will test the general hypothesis that giant kelp detritus is an important source of dietary carbon to suspension feeders, a commonly accepted idea that needs re-evaluation in light of key assumptions that have been made in its support. Our anticipated sampling scheme combined with time-series data on producer biomass collected as part of our long-term core monitoring (Table 1) will enable us to capture this variability, which is generally missed by short-term food web studies involving stable isotope analyses.

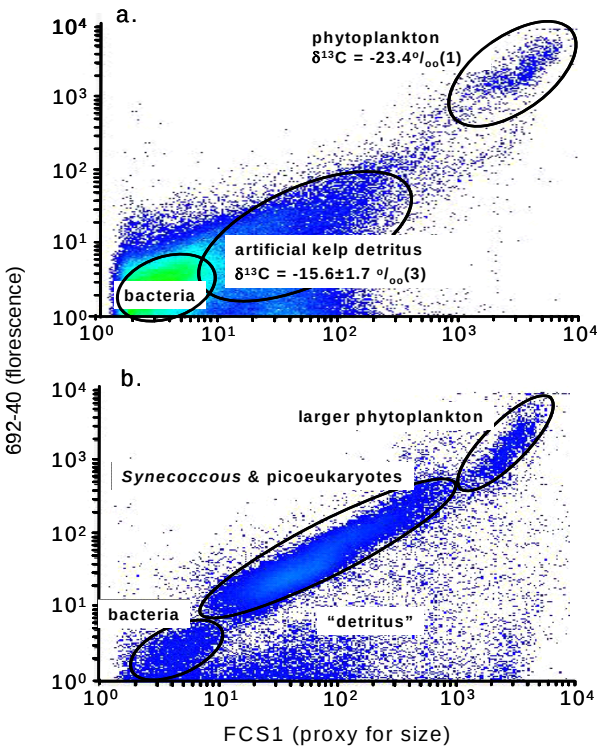


Figure 9. (a) Illustration of the separation of particle classes of natural suspended POM based on size and florescence using the Influx Mariner flow cytometer. Particle classes can be "gated" by optical properties and sorted for isotopic analysis. (b) Separation of laboratory cultured phytoplankton from kelp (*Macrocystis pyrifera*) detritus generated in the laboratory based on optical properties.

Timing and magnitude of nitrogen delivery to giant kelp forests from different sources

We examined sources of nutrients to the kelp forests of the Santa Barbara Channel using time series obtained from an *in situ* nitrate autoanalyzer moored at three of our long-term study sites (Carpinteria, Naples, Arroyo Quemado). The data obtained from this effort provided the first high-resolution (every 30 min) time series of nitrate + nitrite (dissolved inorganic nitrogen, DIN) concentrations for this environment. These measurements showed that the major mechanisms that supplied DIN to the inner shelf of the Santa Barbara Channel varied seasonally and consisted of upwelling, diurnal internal tides, and storm runoff (McPhee-Shaw et al. 2007). Upwelling dominated increases of inner-shelf DIN between March and May accounted for more than half of the annual advective DIN transport to shallow reefs where kelp forests occur (Table 2). In summer, internal waves provided an important source of DIN because they occurred when surface nutrient concentrations were depleted and the other supply mechanisms were inactive. Brief episodes of upwelling became important in late autumn and early winter. DIN inputs from storm runoff, detected as salinity dilution at the moorings and estimated from measurements of stream discharge and nutrient concentration were significant during

winter runoff events. The relative importance of these sources will depend on interannual

Mechanisms for nutrient delivery	Days	Contribution to annual DIN supply: With dilution estimates: Low end-member stream DIN (%)	With dilution estimates: High end-member stream DIN (%)	With hydrologic estimates: Greater ocean volume (%)	With hydrologic estimates: Smaller ocean volume (%)
Year 1: 01 Mar 2001–28 Feb 2002					
Spring upwelling	39	70	68	63	47
Summer internal waves	54	15	15	14	10
Winter upwelling	13	12	12	11	8
Terrestrial storm runoff	6/37*	2	4	12	35
Year 2: 01 Mar 2002–28 Feb 2003					
Spring upwelling	65	81	77	79	70
Summer internal waves	48	9	9	9	8
Winter upwelling	11	7	7	7	6
Terrestrial storm runoff	13/22*	2	7%	4	15

* Days are identified using the moored salinity time series and the hydrographic methods (see text for details).

Table 2. Annual contribution for two sequential years of DIN supplied by four primary mechanisms that advect nitrate into the inner shelf of the Santa Barbara Channel.

variations in rainfall and oceanic conditions.

Building on this work we sought to determine the relative importance of different sources of nitrate to the annual nitrogen needs of the giant kelp *Macrocystis pyrifera* by measuring ambient nitrate concentrations in the kelp forest at Mohawk Reef for 13 months (using the moored nitrate autoanalyzer described above) and characterizing nitrate delivery using water column thermal structure and flow data collected in the forest interior and at its offshore edge (Fram et al. 2008). Rates of net nitrogen uptake by kelp were calculated for the entire forest (using data collected from our long-term studies of kelp net primary production; Table 1 and Theme 2 below), and for a select subset of kelp fronds to isolate vertical and cross-shore differences in nitrogen acquisition. The forest's monthly nitrate supply varied by a factor of 50, while measured net nitrogen acquisition varied only five fold regardless of the method used to measure it. Maximum net nitrogen acquisition rates for fronds in the forest interior were 0.18 mmol N g^{-1} $month^{-1}$ during spring upwelling and declined four fold during autumn until upwelling resumed the following year. Modeled gross nitrogen uptake with consideration of Michaelis–Menten kinetics for nitrate and mass transfer limitation was higher than observed net acquisition except during the warm stratified summer and autumn months, when net acquisition exceeded modeled gross uptake (Figure 10). This shortfall indicates that the kelp forest received over half its nitrogen from sources other than nitrate (such as ammonium from epibionts) during this period. Most of the nitrate in the forest was delivered as a result of upwelling-favorable winds and convection. Internal waves and local streams

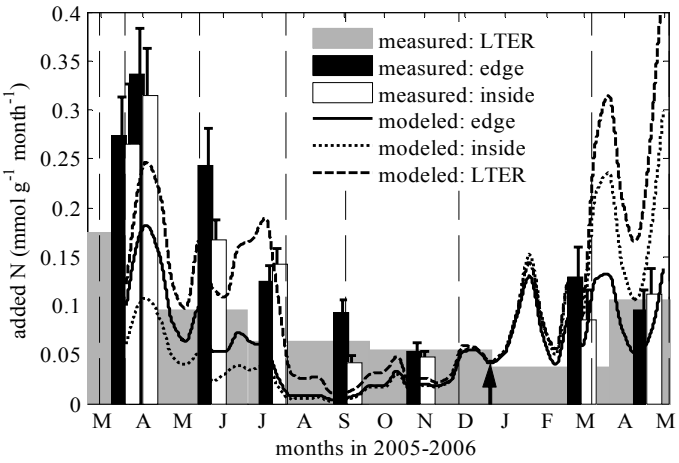


Figure 10. Time series of measured acquisition and modeled uptake of nitrogen in mmol (wet g) $^{-1}$ $month^{-1}$ by growing canopy fronds at the edge and inside the Mohawk kelp forest, and of all fronds in a 40 m x 40 m area of the interior of the forest (LTER) for the period 21 March 2005 through 30 April 2006.

contributed 9% of the nitrate delivered to the forest on an annual basis and 20% during stratified periods over the duration of the study. Kelp used less than 5% of the nitrate supplied to the forest. Nitrate delivery to this modest-sized kelp forest was roughly equivalent between alongshore (45%) and cross-shore flows (55%), which distinguishes it from large kelp forests in which cross-shore flows dominate exchange.

Carbon and nitrogen linkages between giant kelp forests and sandy beaches

Wave-exposed sandy beaches represent a classic example of a subsidized ecosystem where *in situ* primary production is low and biotic communities are primarily supported by imported organic material from other ecosystems. Subsidies of drift macroalgae or wrack exported from kelp forests to beaches in the Santa Barbara Channel can exceed 500 kg m^{-1} y^{-1} for *Macrocystis pyrifera* alone (Dugan et al. *in prep*). These inputs from kelp forests to beaches exhibit strong temporal variation in response to pulse and press drivers, such as seasonal variation in wave climate, sediment supply and ENSO events, as well as kelp forest condition (Revell et al. *in press*).

Our ongoing investigations of the role of kelp wrack subsidies in beach ecosystems indicate that they support a substantial component of the beach food web. Spatial variation in wrack abundance propagates up through invertebrate detritivores (Figure 11) to predatory shorebirds, including the Western snowy plover, a threatened shorebird that breeds on beaches (Dugan et al. 2003). Temporal variation in the supply of kelp wrack to beaches in response to press and pulse drivers is expected to have important consequences to the beach food web. For example, we found a doubling of invertebrate consumer richness in 8 weeks following weekly additions of fresh *Macrocystis* to one of our beach study sites. Consumption of kelp wrack can be rapid as talitrid amphipods alone were estimated to consume kelp wrack at a rate of 18 kg m^{-1} of shoreline in one month, which constituted about ~40% of the measured input (Lastra et al. 2008).

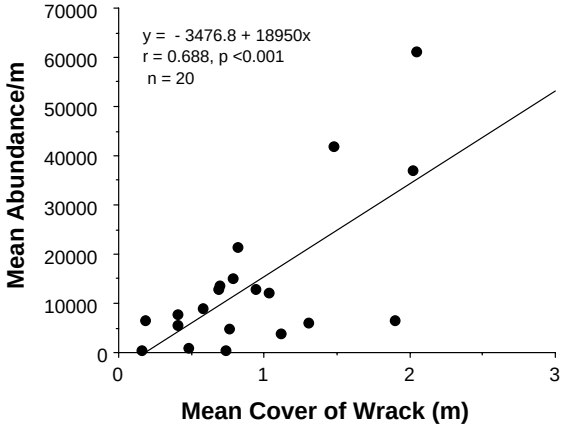


Figure 11. Relationship between the biomass of kelp wrack and the abundance of talitrid amphipods.

This rapid processing of macroalgal wrack by invertebrate detritivores and its decomposition and subsequent nitrogen mineralization by bacteria can lead to high concentrations of dissolved nitrogen in intertidal porewater (>1000 μM, Figure 12), particularly on beaches with heavy wrack accumulation (Dugan et al. *in prep*). Highest DIN concentrations (>200 μM) in intertidal porewater were found in late summer and fall when sand accumulation on Santa Barbara

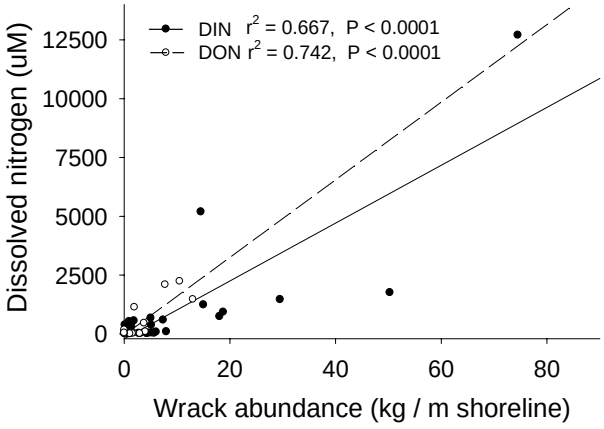


Figure 12. Relationships between the biomass of macroalgal wrack and dissolved inorganic nitrogen and dissolved organic nitrogen in beach pore water.

beaches is greatest. Much lower DIN values (<100 μM) occurred in winter and spring when sand levels are typically low. The interaction of press and pulse drivers such as tidal forcing/drainage, erosive events and sediment dynamics are expected to strongly affect release and transport of dissolved nutrients from beach aquifers, as will interactions with terrestrial groundwater sources when present. Planned studies of the decomposition and mineralization of kelp wrack, and the timing and magnitude of the release of intertidal porewater will be used to evaluate the significance of this potential nitrogen source to coastal waters and kelp forests.

Our ongoing research in this area seeks to understand how beaches function as both filters and sources of regenerated nutrients to the coastal ocean. Similar to wetlands and estuaries, beaches may act as a filters or buffers for anthropogenic nutrient loads conveyed in groundwater flowing from land to the ocean. As indicated above, the beach ecosystem may also represent a nutrient source to coastal ocean primary production as wave and tidal activity circulates organic materials, such as wrack and phytoplankton, through beach sand where they are decomposed and mineralized. The dynamics of release and the transport rates of these dissolved nutrients from the shallow unconfined aquifers of sandy beaches to the nearshore ocean will be studied using an array of sampling wells and instrumentation at beach sites that differ in freshwater influence through different tide cycles.

The ability of beach ecosystems to accumulate and process wrack material can be significantly affected by abiotic press and pulse drivers that interact with human activities (Schlacher et al. 2007). Our finding of a significant relationship between wrack abundance and dry beach width (Revell et al. *in press*) suggests that when dryer upper beach zones are narrow or absent, wrack accumulation and its availability to beach consumers is decreased. Of particular concern in this regard is climate-induced sea level rise which is expected to increase coastal erosion, reduce beach width and thereby negatively affect beach food webs. Coastal armoring, a common societal response to beach erosion, is expected to expand with sea level rise. However, we found that beaches with coastal armoring were significantly narrower and had 1-3 orders of magnitude less wrack compared to adjacent unarmored beaches (Dugan et al. 2008). Shorebird use of armored sections was also significantly lower. Our studies of the effects of coastal armoring on intertidal beach communities are ongoing and should provide important insights into interactions between humans and climate change and their ecological consequences to linkages between sandy beach and kelp forest ecosystems.

THEME 2: The direct and interactive effects of key press and pulse drivers on kelp forest community structure and function

Role of disturbance and N supply on giant kelp abundance and NPP

Net primary production (NPP) is fundamental to life on Earth as it influences nearly all ecosystem processes. As such, NPP constitutes a critically important ecosystem function and determining its patterns and principal environmental drivers is justifiably one of the core research areas shared by all sites in the LTER network. NPP is influenced by disturbance-driven fluctuations in foliar standing crop (FSC) and resource-driven fluctuations in rates of recruitment and growth, yet most studies of NPP have focused primarily on factors influencing growth. We have been measuring NPP, FSC, recruitment, and growth rate of the giant kelp, *Macrocystis pyrifera* at three kelp forests in the Santa Barbara Channel since May 2002 to determine the relative roles of FSC, recruitment and growth rate in contributing to variation in annual NPP (Rassweiler et al. 2008). Our results show that giant kelp forests are among the most productive ecosystems in the world, and that relative to terrestrial forests high levels of NPP result from a small FSC that grows rapidly and turns over ~ 7 times per year (Reed and Brzezinski 2009). Despite its high growth rates we found that the initial FSC present at the beginning of the growth year and the recruitment of new kelp plants during the year

explained 63% and 21% of the inter-annual variation observed in NPP, respectively (Reed et al. 2008). The previous year's NPP and disturbance from waves collectively accounted for 80% of the inter-annual variation in initial FSC. No correlation was found between annual growth rate (i.e., the amount of new kelp mass produced per unit of existing kelp mass) and annual NPP (i.e., the amount of new kelp mass produced per unit area of ocean bottom), largely because annual growth rate was relatively constant compared to initial FSC and recruitment, which fluctuated greatly among years and sites. Although growth rate was a poor predictor of variation in annual NPP, it was principally responsible for the high values observed for NPP by *Macrocystis* (up to 4.4 kg dry mass m^{-2} y^{-1}). These high mean values reflected rapid growth (average of ~ 2% $^{-d}$) of a relatively small standing crop (maximum annual average = 444 g dry mass m^{-2}) that replaced itself about seven times per year. Our observations of continuously high nitrogen content in kelp (generally above 1%) coupled with our finding that growth was unrelated to the concentration of DIN in seawater at two of our three sites (Figure 13) suggests that growth has rarely been nitrogen limited since our study began. These findings contrast with those of other investigators who studied kelp growth during prolonged conditions of nutrient stress associated with the 1982-83 El Niño, and they lend support to the contention that the importance of intra-annual variation in nitrogen supply in determining kelp growth and production depends on the state of longer-term climatic regimes.

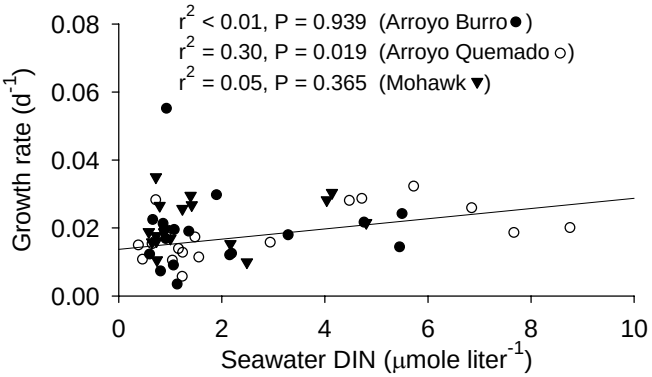


Figure 13. The relationship between specific growth rate and the ambient concentration of dissolved inorganic nitrogen (DIN).

Our time series data on biomass and NPP by giant kelp (Rassweiler et al. 2008) are unique in that we know of no other data for macroalgae that match their temporal and spatial resolution (monthly measurements ongoing since 2002 at three sites). Such resolution is needed to detect directional changes in kelp biomass and NPP associated with long-term press drivers (e.g., global climate change) in the presence of more variable fluctuations associated with short-term pulse drivers (e.g., winter storms). The large effort associated with collecting data on kelp biomass and NPP limit the number of sites that we can sample, which restricts our ability to place our results into a larger regional context. Motivated by this limitation we analyzed our time series data to evaluate the validity of using a common and readily measured population variable (kelp frond density) to estimate the more difficult to measure variables of standing crop and NPP. We found that standing crop was strongly correlated to frond density ($r^2 = 0.79$), and that data on frond density collected in summer were particularly useful for estimating annual NPP, explaining nearly 80% of the variation in the NPP from year to year (Reed et al. 2009). Currently we are applying these relationships to annual time series data on frond density collected at 9 of our long-term monitoring sites as well as to similar data collected by investigators at sites in other regions to test our predictions concerning the role of disturbance in determining the magnitude and variability of annual kelp NPP.

Limits to the spatial extent of data that are routinely collected by divers have led us to search for additional means of investigating regional patterns in kelp biomass and NPP. With additional funding from NASA we have been exploring the use of high-resolution satellite imagery (SPOT 5 and Landsat 5 & 7) to investigate regional dynamics of giant kelp biomass and production (Figure 14). Our monthly measurements of kelp biomass

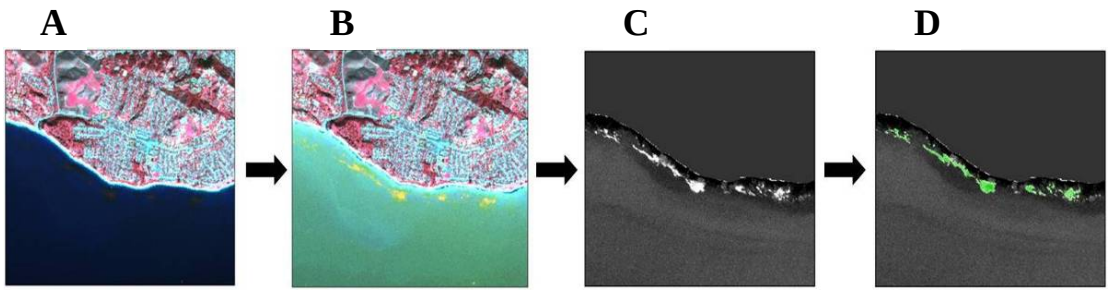


Figure 14. Four steps in the procedure for canopy cover delineation from SPOT 5 imagery. (A) False color SPOT image after geometric and atmospheric corrections have been performed; (B) Resampled image after land and cloud areas have been masked out; (C) PC band 2 (see Table 1 for band loadings), kelp is easily differentiated in this image because kelp's spectral signature closely matches the second mode of variability of the principal components rotation; (D) PC band 2 after the threshold, manual edits, and winnowing filter have been applied. Pixels of kelp canopy are displayed in green.

and frond density in fixed plots collected by divers were strongly correlated with satellite determinations of Normalized Difference Vegetation Index (NDVI) signals of those plots ($r^2 = 0.77$). We are using this relationship to examine the variability of kelp biomass across multiple scales (pixel, plot, kelp bed, and region) and to explore the degree to which the relationship between plot-scale changes (as measured by divers) and bed-scale changes (as assessed remotely by satellites) varies with kelp bed location, kelp bed size and the location of plots within a kelp bed (Cavenaugh et al. *in review*). In addition, we are in the process of extending this regional time series of kelp cover and biomass backward in time (1984 to 2003 and maybe to the present) using the recently available Landsat 5 and 7 imagery. Our initial results show that we can successfully separate the Landsat spectral bands to quantify kelp cover fraction for each 30 m Landsat pixel. By using our intensive diver measurements to parameterize satellite estimates of kelp biomass, we hope to better understand patterns and drivers of giant kelp biomass and production across a spectrum of spatial and temporal scales.

<u>Interactions between the forest and its flow environment and their consequences on kelp and associated biota</u>

Pulse and press drivers that alter the biomass of giant kelp change the physical structure of the kelp forest, which can have cascading effects on fluid flow, light attenuation and the delivery of waterborne subsidies. These interactions in turn can influence the biotic structure and ecological functioning of the kelp forest community. To examine the extent to which the forest interacts with impinging currents we measured the flow characteristics inside and surrounding the kelp forest at Mohawk Reef using an array of 13 acoustic Doppler current profilers. We found that velocities were damped by as much as 60% in the interior of the forest and accelerated by as much as 200% along the forest's outer boundary as flow was shunted around the forest (Gaylord et al. 2007). We also found that the shading by the kelp canopy caused as much as a 90% reduction in fraction of surface light reaching the bottom in the interior of the forest relative to the edge of the forest

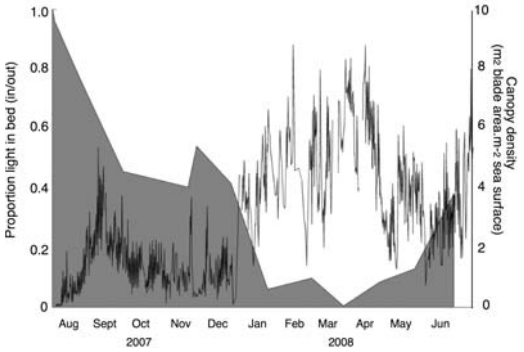


Figure 15. Ratio of bottom irradiance in the interior of the kelp forest to that outside the kelp forest. Shaded area denotes the density of the surface canopy of giant kelp.

(Figure 15). These physical features bear on the performance of kelp and other forest organisms that rely on light for photosynthesis and/or currents to deliver nutrients and food. For example, we found that kelp fronds on the seaward edge of the forest were longer, bushier (i.e., had larger, more numerous blades per unit length) and had higher overall growth rates than fronds growing in the interior of the forest (Stewart et al. 2009). Carbon and nitrogen accumulation by edge fronds was also higher, which fueled growth rates of edge fronds that were nearly twice as high as interior fronds when the kelp canopy was densest. Thus, the growth and tissue chemistry of *M. pyrifera* in the kelp forest depended on the extent to which the kelp forest modified the physical conditions within it.

We have evidence that giant kelp similarly affects the performance of kelp forest consumers. The colonial bryozoan *Membranipora serrilamella,* is a ubiquitous filter feeding invertebrate that lives on the blades of giant kelp. We have found that abundance and frequency of occurrence of *Membranipora* were as much as two orders of magnitude higher on the outside edges of forests compared to their interiors (Figure 16), due to higher rates of recruitment and growth at the forest edge (Arkema 2008). Lower rates of recruitment and growth in interiors of forests were attributed to measured reductions in flow and particle flux caused by the presence of giant kelp. Feeding success was highest at intermediate flow speeds, and *Membranipora* abundance and growth rate were greatest at sites where water moved at intermediate flow speeds the majority of the time (Arkema 2009). Collectively our results demonstrate how the physical structure of the kelp forests interacts with its surrounding environment to influence the biotic structure of the kelp forest community, and they highlight the importance of environmental drivers of giant kelp in influencing the entire kelp forest community.

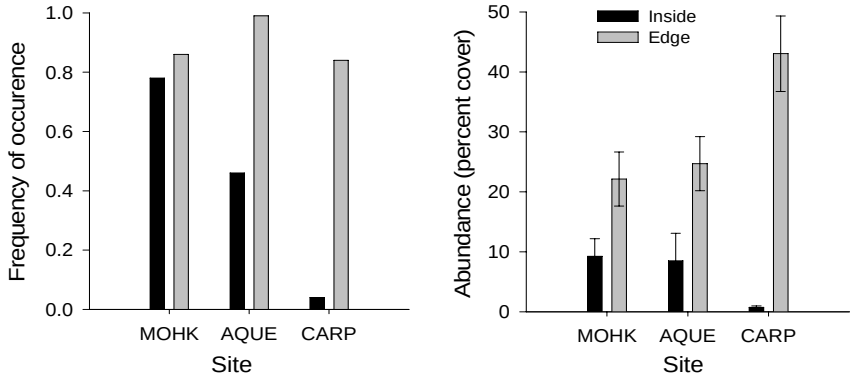


Figure 16. The frequency of occurrence and percent cover of *Membranipora* on kelp blades inside and at the outside edge of the kelp forests at Mohawk Reef (MOHK), Arroyo Quemado (AQUE) and Carpinteria Reef (CARP).

Effects of wave disturbance on food web structure

While the last twenty years have witnessed a large increase in research detailing the general structure of ecosystem food webs in nature (Dunne2006), we know much less about how abiotic and biotic forces shape the structure of food webs at the community level. This is a particularly pressing need, as in the next century climate change will influence the frequency and intensity of a variety of press and pulse disturbances in marine ecosystems. Indeed, in California the last fifty years have witnessed an increase in both the frequency and intensity of winter storms (Graham and Diaz 2001, Bormoski et al. 2002). Here at the SBC LTER, we are using our long-term data to examine how these disturbances both directly and indirectly alter the structure of kelp forest food webs.

We are using structural equation modeling in conjunction with data from our ongoing long-term monitoring of kelp forest community structure at 11 sites to examine both direct and indirect effects of wave disturbance on the structure of the kelp forest food web.

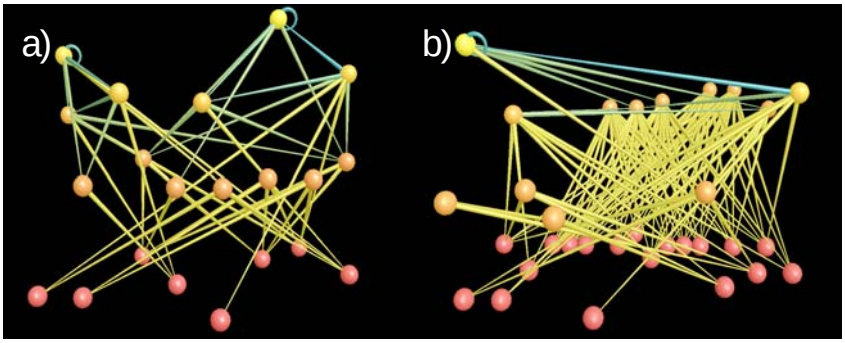


Figure 17. Food webs from Carpinteria Reef in (a) 2003 and (b) 2007. The nodes (indicated by spheres) represent species and the lines represent interactions between nodes. Note that webs differ in species richness as well as in the number and pattern of trophic links.

Wave height projections for our sites are obtained from the Coastal Data Information Program (CDIP). Drawing from available literature, institutional archives and conversations with experts we have been able to discern predator-prey relationships between all taxa that we have encountered in our long-term kelp forest monitoring. We are using this information along with the data to determine the network structure of the food web for each site in every year sampled. We have found that these webs differ greatly in topology in both space and time (Figure 17). With these webs, we can calculate different network metrics to describe each individual web (e.g., richness, density of trophic linkages, and ratios of biomass and richness between different trophic groups).

We have constructed a general structural equation model that independently examines the direct and indirect effects of waves on each of these structural metrics. For each structural metric, our model contains a direct path between average monthly peak wave orbital velocity (i.e., the amount of strong wave disturbance) and the structural variable. It also contains an indirect path; wave disturbance connects to kelp frond density and kelp frond density is then allowed to influence a given structural metric. We have also included a variable representing the cover of sand that works the same way as the wave disturbance variable. Disturbance by sedimentation can have large impacts on the structure of rocky reefs, and alter the composition of the local biota (Reed et al. 2008). In some models, we are using multiple structural metrics with paths connecting them in a manner consistent with our knowledge of food web theory. For example, linkage density often positively scales with species richness. Similarly, the number of intraguild interactions increase with the richness of species in higher level trophic groups.

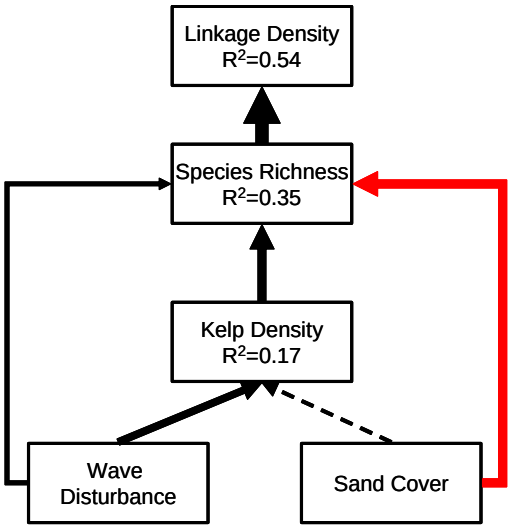


Figure 18. Results from a structural equation model linking different forms of disturbance with kelp density, species richness, and food web linkage density. Path width is proportional to effect size. Red paths are negative. Black paths are positive. Dashed paths are non-significant at p = 0.05.

Our results to date show that wave disturbance directly and indirectly increased local species richness and the density of links (# of links / # of species) of food webs (Figure 18). Site-years with high wave disturbance had higher species richness. High wave disturbance also removed large adult kelp, and led to dense

thickets of juvenile kelp. Higher kelp density, in turn led to higher species richness. Higher species richness also led to higher linkage density, which is consistent with theory.

Future models will explore other structural variables to obtain a more detailed understanding of how wave disturbance alters the structure of kelp forest food webs. We also plan to decouple the effect of physical structure of kelp from its role as a food source by using satellite imagery to estimate total kelp biomass available to consumers. Our projections should provide much needed insight into the consequences of altered disturbance regimes caused by climate change.

State changes and resilience of kelp forest communities in response to pulse and press drivers

Kelp forest landscapes tend to consist of mosaics of patches in distinct community states, and switches between states within each patch are often sudden and dramatic. These patterns are commonly thought of within the framework of phase shifts and alternative stable states, but they also have important implications for understanding how the ecosystem responds to pulse and press drivers. If alternative stable states are present, then the response of the system to a change in one driver will be dependent not only on the condition of the other drivers, but also on the current state of the ecological community. Long-term research in this case is crucial because each community state can persist for many years and the full behavior of the system cannot be understood without studying how each state responds to different environmental drivers.

The effect of sea urchins on kelp provides a well understood example of the interaction between community state and environmental drivers. When present at high densities, sea urchins actively graze and prevent the establishment of kelp and other organisms, whereas at low densities they remain sedentary and feed passively by capturing drifting pieces of algal detritus. Because of this behavioral switch, an environmental driver that promotes kelp recruitment will have little effect on kelp abundance when sea urchin densities are high, but lead to large increases in kelp abundance when sea urchins are rare. We have used LTER monitoring data to show that this feedback is important in Santa Barbara, as giant kelp is only present when urchins are below a certain threshold density (28 urchins m^{-2}), regardless of other conditions (Figure 19). Although the effect of sea urchins on kelp is best known, we have shown that their presence has important effects on other taxa, maintaining low densities of sessile invertebrates and algae and clearing enough bare space that the space competition which typifies these sessile communities is minimized (Arkema et al. *in press*).

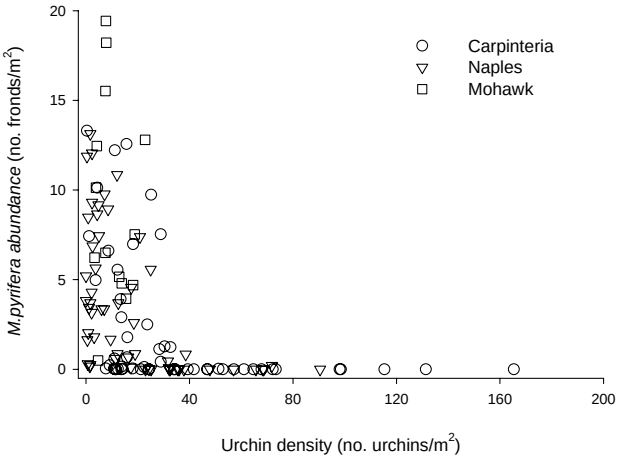


Figure 19. The relationship between kelp frond density and sea urchin density at three reefs in the Santa Barbara Channel. Data represent mean densities observed on a given transect during a given year.

We have also been studying another important shift between communities that appears to be alternative stable states, in which a macroalgal dominated community is replaced by one dominated by the filter feeding sea cucumber *Pachythyone rubra*. Such shifts in community structure have negative effects on primary production, as autotrophs are

replaced by heterotrophs, but they also have cascading effects on the entire food chain, with the loss of macroalgae leading to a reduction in micro-crustaceans and in their associated fish predators. We have been studying shifts between these states at a number of sites off Santa Cruz Island in the Santa Barbara Channel and have documented very rapid shifts and also the persistence of a single state for many years (Figure 20).

We have experimentally explored the interactions between macroalgae and *P. rubra* to determine the mechanisms that explain the shifts between community states and the maintenance of each state (Rassweiler 2008). We found that the sea cucumbers and macroalgae compete strongly for space, which is consistent with results from analogous systems. More surprisingly, we found that the sea cucumbers consume algal spores at a sufficient rate to have a strong effect on algal settlement. This web of interactions, in which one species consumes its competitor (known as intraguild predation) is often associated with alternative stable states. We have used analytical models and spatially explicit simulations to show that in this system intraguild predation reinforces the *P. rubra* aggregations, and may even create alternate stable states (Rassweiler 2008).

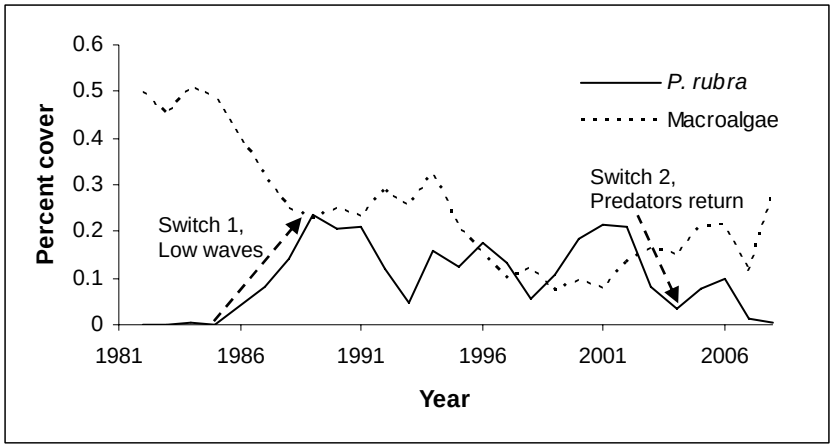


Figure 20. Mean cover of *Pachythyone rubra* and macroalgae at SBC LTER sites at Santa Cruz Island. Switches in 1986 and 2003 are marked with dotted arrows.

We have analyzed our time-series of *P. rubra* and macroalgal abundance alongside long term data on potential physical and biological drivers. We found that the switch into the high *P. rubra* phase was most likely triggered by a period of low waves (Figure 20). Because macroalgae rely on waves and water motion to compete for space, their competitive ability was reduced during this period and *P. rubra* was able to establish. Although the low waves were only temporary, representing a pulse disturbance, other mechanisms, such as intraguild predation, were sufficient to maintain *P. rubra* dominance once it was established. We found that a different mechanism explained the end of the high *P. rubra* state, with the sea cucumbers' reduction coinciding with the appearance of its major predator, the sunflower sea star *Pycnopodia helianthoides.* This predator represents a press disturbance in the system, and its continued presence explains the continued low density of sea cucumbers. It appears that interactions between the key press and pulse drivers are important in structuring this system, as the initial switch to *P. rubra* dominance was only possible because of the absence of its main predator. A similar pulse disturbance of low waves would be unlikely to allow *P. rubra* to increase if it occurred today given the current levels of predation.

Our work on kelp-urchin state change and our study of shifts between macroalgal and filter feeder dominated communities both mesh well with a broader cross-site LTER interest in phase shifts and alternative stable states. To this end we have been collaborating with scientists from other LTER sites (Jornada, California Current Ecosystem, Moorea Coral Reef, Palmer Station and Harvard Forest) on general processes and mechanisms promoting phase shifts in ecological systems. At an Ecotrends working group in Spring 2009, we initiated two cross-site manuscripts. The first illustrates a new method for detecting phase shifts in ecological communities, and applies it to datasets

from several LTER sites, including two from SBC, one on kelp dynamics and the second on *Pachythyone rubra* populations. That first manuscript is well underway and should be ready for editing at the 2009 ASM. The second manuscript deals with how the detection of phase shifts depends on the spatial scale being sampled and requires observational data on phase shifts that have been collected at multiple spatial scales. We are currently compiling data for this analysis both from within and outside the LTER network.

THEME 3: The indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between structure and function

Direct and indirect effects of disturbance-driven fluctuations in giant kelp abundance on benthic community structure

The giant kelp *Macrocystis pyrifera* is considered both a foundation species (*sensu* Dayton 1975) and an ecosystem engineer (*sensu* Jones et al. 1994) because not only does it provide food and shelter for a diverse array of species, but it also significantly alters the physical environment in which it lives. Hence press and pulse drivers that affect the abundance of giant kelp should have corresponding effects on species that associate with it. Kelp forest communities are characterized by a trophic structure that is distinct to shallow reef ecosystems in that the primary space holders (i.e., macroalgae and sessile suspension feeding invertebrates) occupy different trophic levels and thus do not compete for resources other than space. However, competition *within* the two space holder groups for other resources may indirectly affect the strength of competition for space *between* them. For example, shade from the canopy of the giant kelp negatively affects understory algae, which raises the possibility that giant kelp indirectly facilitates sessile invertebrates, via suppression of understory algae. We took a two-fold approach to examine this phenomenon (Arkema et al. 2009). First, we experimentally removed giant kelp from 40 m x 40 m study plots and measured the responses of understory algae and sessile invertebrates. We found a negative effect of giant kelp on both light availability and understory algal abundance and a positive effect on the abundance of sessile invertebrates, which was consistent with an indirect effect mediated by shade from the kelp canopy. Secondly, because frequent disturbance causes kelp populations to fluctuate greatly in space and time, we used observational data on kelp forest community structure from long-term monitoring sites to examine whether the interactions among kelp, understory algae and sessile invertebrates observed experimentally in space led to predictable patterns over time. We found that interannual variability in the abundances of understory algae and sessile invertebrates were significantly and positively related to interannual variability in the abundance of giant kelp ($r^2 = 0.74$, $P < 0.001$ for understory algae and $r^2 = 0.46$, $P = 0.03$ for sessile invertebrates). Results from structural equation modeling indicated that giant kelp negatively affects understory algae via canopy shading, understory algae negatively affects sessile invertebrates through space competition, and giant kelp indirectly facilitates sessile invertebrates (Figure 21). In fact, the magnitude of the

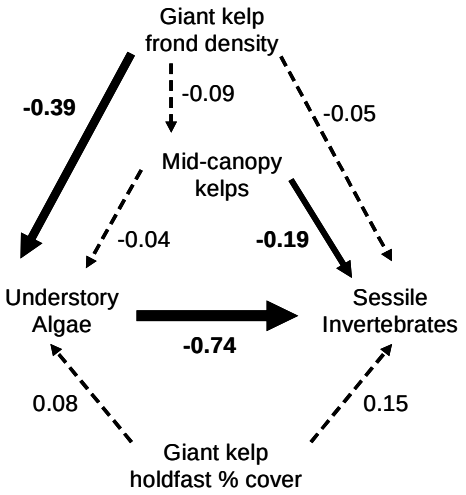


Figure 21. The fitted competition and facilitation model used to estimate the strength of direct and indirect effects. Values are standardized coefficient estimates. Solid lines indicate significant paths ($P < 0.05$). Dashed lines are non-significant.

indirect effect of giant kelp frond density on sessile invertebrates (-0.39 x -0.74 = 0.29), was nearly six times greater than the magnitude of the direct effect (= -0.05). The coefficient for the path representing the direct effect of giant kelp frond density on sessile invertebrates was not significantly different from zero, nor were the paths between the percent cover of giant kelp holdfasts and the percent cover of understory algae and sessile invertebrates, suggesting that the significant effects of kelp resulted from shading by kelp fronds rather than competition for space by kelp holdfasts. Our results suggest that the dynamic structure of the kelp forest community is driven in large part by variability in the abundance of a single structure-forming species (giant kelp) that has indirect positive, as well as direct negative effects on associated plants and animals.

Disturbance, assemblage structure and the partitioning of primary production among giant kelp, understory macroalgae and phytoplankton

Giant kelp forests are highly productive ecosystems, rivaling those of tropical rain forests. This productivity and its associated standing biomass, however, vary greatly both within and among years in large part due to disturbance from waves (Reed et al. 2008). Such variation in turn, affects the entire kelp forest assemblage of primary producers, which are negatively affected by kelp canopy shading (Arkema et al. 2009). To date, estimates of kelp forest production have focused mainly on *Macrocystis*, and have not considered the diverse community of phytoplankton and understory benthic algae. Strong competition for light with giant kelp in the forest may cause populations of these two groups of autotrophs to vary out of phase with *Macrocystis*, which may serve to dampen the variability in ecosystem production by kelp forests. To the extent that *Macrocystis* dominates total reef ecosystem NPP, variation in *Macrocystis* canopy will drive corresponding variation in total ecosystem NPP. Alternatively, if NPP of understory algae and/or phytoplankton increases in response to reduced *Macrocystis* canopy, then variability in ecosystem NPP will be reduced. The amount of such compensatory productivity will depend upon the magnitude and temporal lag in the production of understory algae and phytoplankton to the more favorable light conditions associated with kelp loss following disturbance. Phytoplankton are likely able to respond rapidly as the biomass of phytoplankton in the kelp forest is determined by larger scale processes that affect the regional production and transport of phytoplankton (see Theme 1 Transport of offshore shelf C and N to the inner shelf). In contrast, the recruitment and growth of understory algae are influenced by conditions within the forest, and because of their slower growth rates and seasonal recruitment NPP by understory algae in the kelp forest may lag substantially behind that of phytoplankton following kelp loss.

To examine the role of disturbance in partitioning NPP among different groups of kelp forest producers we developed methods for measuring NPP by understory algae *in situ* (Miller et al. 2009) and used these methods to compare rates of NPP by understory macroalgae with those by phytoplankton and giant kelp in an area where giant kelp was removed to an adjacent area where it was left in place. The study was done at Mohawk Reef over a 17-month period in 2007-2008 when wave disturbance caused substantial variability in *Macrocystis* standing crop and production. We hypothesized that the *Macrocystis* canopy would negatively affect the productivity of understory macroalgae and phytoplankton, and that these effects would vary with *Macrocystis* standing crop. We predicted that understory algae, unlike phytoplankton, would be unable to respond immediately to reductions in *Macrocystis* shading, and one of our goals was to estimate the magnitude of this time lag. Finally, we compared NPP by *Macrocystis* with that by understory macroalgae and phytoplankton to determine whether natural fluctuations in *Macrocystis* biomass led to similar fluctuations in the NPP of the entire kelp forest ecosystem.

We found strong evidence that the presence of the giant kelp suppressed production by phytoplankton and understory algae (Miller et al. i*n prep*). As predicted, increased NPP

by phytoplankton occurred immediately following disturbance-induced reductions in the kelp canopy, while NPP by understory algae displayed a substantial time lag in response to kelp loss due to the time required to increase its biomass via recruitment and growth. Importantly, we found that in the absence of giant kelp, NPP by phytoplankton and an established understory was comparable to that of an established kelp forest community (Figure 22a) for much of the study. Somewhat surprising was our finding that phytoplankton and understory algae contributed on average about one third of ecosystem NPP within the intact forest at the *Macrocystis* canopy control site (Figure 22b).

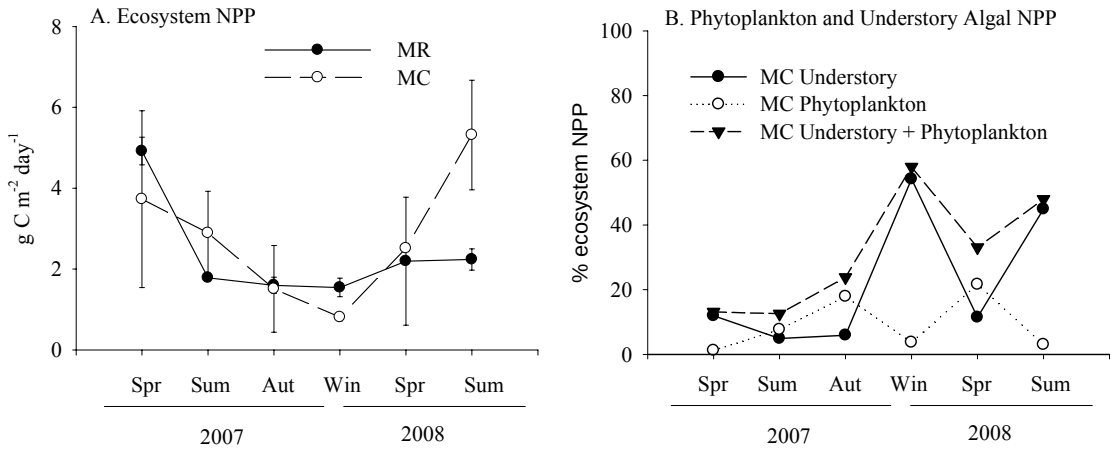


Figure 22. (A) Mean (± SE) ecosystem NPP, including *Macrocystis*, understory, and phytoplankton NPP at the *Macrocystis* removal (MR) and *Macrocystis* control (MC) sites at Mohawk Reef. (B) Percentage of ecosystem NPP by phytoplankton and understory algae with the kelp forest at the *Macrocystis* control (MC) site.

These results illustrate how indirect effects of pulse and press drivers can influence important aspects of kelp forest structure and function and how the structure of kelp forests as defined by the biomass and species composition of their autotrophs feeds back to influence the critically important ecosystem function of net primary production.

Feedbacks between benthic diversity and grazing intensity in giant kelp forests

In seeking to understand the complex dynamics of communities, researchers have typically concentrated on factors that either regulate community structure or community function. Nowhere has this dichotomy been more evident than in biodiversity research, where separate research traditions have attempted to tease apart either the causes or the consequences of biodiversity. Both are inextricably linked. For example, theories such as the Intermediate Disturbance Hypothesis state the biodiversity is maximized at

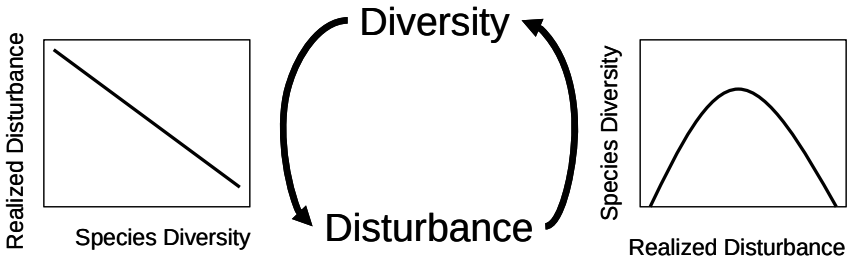


Figure 23. Hypothesized feedbacks between species diversity and disturbance. Diversity of an assemblage determines how much disturbance results from a particular event (e.g., highly diversity communities will potentially experience less disturbance). The amount of disturbance realized by a community in turn feeds back to alter the diversity of the subsequent assemblage.

intermediate levels of disturbance (Connell 1978). On the other hand, biodiversity ecosystem function research has shown repeatedly that high levels of biodiversity can actually reduce the intensity of disturbance (Hillebrand and Cardinale 2004, Hughes and Stachowicz 2004). We hypothesize that these two relationships form a feedback between species diversity and disturbance (Figure 23).

Within kelp forests, biological disturbance by sea urchins can significantly alter levels of primary productivity. Sea urchins prefer to feed on kelp detritus, but when starved for drift kelp they change their mode of feeding to one of active grazing. Dense aggregations of grazing sea urchins are common in kelp forests worldwide and their ability to denude the bottom substrata of most sessile species has been well documented. However, yet to be determined is the extent to which the diversity of the benthic assemblage that sea urchins attack influences their effect on the structure of that assemblage and the extent to which the realized amount of disturbance to the assemblage in turn feeds back to alter the diversity of the recovered community by altering recruitment, growth, and species interactions.

To investigate the feedbacks between sessile species diversity and sea urchin disturbance, we initiated an experiment in summer 2009 in which we manipulated densities of the purple sea urchin (*Strongylocentrotus purpuratus*) in caged 0.5 m^2 plots that varied in sessile species diversity. Densities of sea urchins were augmented within the caged plots in a response surface design such that plots at all levels of diversity were subjected to a complete range of grazing intensity. The grazing component of this experiment was run for three weeks, after which time we removed the sea urchins and recorded changes in percent cover and species richness of sessile organisms within each plot. We will continue to monitor the recovery of the benthic community in plots over the next year. In this manner, we can examine how initial species diversity alters the impact of grazing, as well as how variation in realized disturbance (e.g., amount of cover removed) alters future changes in species diversity.

Long-term experiment: Implications of climate change on kelp forest structure and function

Modeling and correlative analyses of our long-term data coupled with cause and effect relationships gleaned from an assortment of short-term mechanistic experiments are providing us with considerable insight into our overarching question of *How do abiotic drivers acting over different spatial and temporal scales influence kelp forest structure and function and its interactions with adjacent ecosystems?* Longer-term manipulative experiments conducted at ecologically relevant temporal and spatial scales offer a powerful means of verifying predictions generated by our correlative analyses and short-term experiments. Because the giant kelp *Macrocystis* extends throughout the water column it is easily dislodged by large waves associated with winter storms. With this in mind we initiated a long-term experiment in January 2008 to test an assortment of predictions concerning the consequences of consistent annual kelp loss arising from increases in the frequency and intensity of winter storms, which is a trend that has been observed in California over the last 50 years (Graham and Diaz 2001, Bormoski et al. 2002).

To simulate the consequences of increased storm activity we remove all giant kelp once per year in winter from permanent 40 m x 40 m plots at four of our long-term study sites (Arroyo Quemado, Naples Reef, Mohawk, and Carpinteria Reef). Adjacent 40 m x 40 m plots at each site where kelp is left undisturbed serve as controls (Figure 24). These sites vary in wave exposure and level of sea urchin grazing. As such, we hope to gain valuable insight over the long term with respect to how the effects of selectively removing giant kelp vary with different levels of physical and biological disturbance.

We are following changes in the biological structure (species abundance and richness of algae, invertebrates and fish), and various ecosystem processes (e.g., NPP by

macroalgae, detrital accumulation) twice per season in fixed transects and quadrats located in each plot. We have been developing a non-destructive approach for examining patterns of understory NPP using species-specific allometric relationships (to estimate biomass) coupled with a bio-optical model. Our bio-optical model incorporates algal biomass, photosynthetic efficiency (derived from laboratory derived photosynthesis vs. irradiance curves for ~20 species that comprise over 95% of the biomass), and photosynthetically active radiation measured once per minute by sensors anchored to the bottom in each kelp control and removal plot.

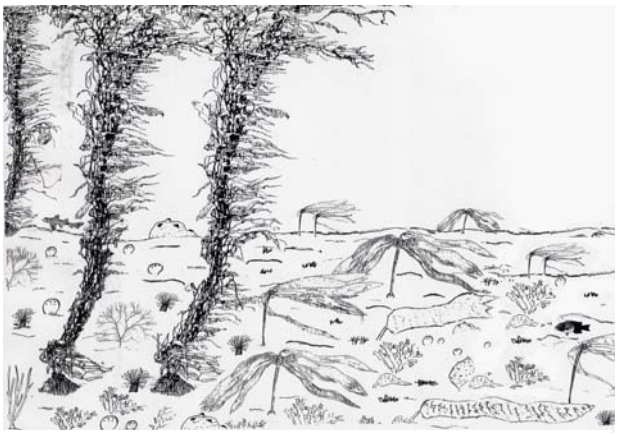


Figure 24. Schematic of the long-term kelp removal experiment showing a giant kelp removal plot with abundant understory kelps and algae on the right and a kelp canopy control plot with giant kelp and a sparse understory on the left.

Our initial results show that giant kelp is among the first species to colonize in spring following its removal in the preceding winter. Dense thickets of young giant kelp have colonized sites with low grazing in each of the first two years. We hypothesize that colonization by giant kelp into the kelp cleared plots will decrease over time as other understory species become established and monopolize light and space. Such changes will undoubtedly influence a diverse assemblage of kelp forest consumers that depend directly and indirectly on giant kelp for food and/or shelter.

In addition to examining potential consequence of climate change, the long-term removal of giant kelp will also provide a wealth of information on how the kelp forest system responds in the absence of its foundation species. Moreover, the design of our experiment (in terms of plot size and replication among sites) allows it to serve as a template for both short and long-term investigations that explore a wide variety of ecological issues and questions pertaining to the presence (or absence) of giant kelp. Indeed, our current studies of kelp forest food webs and feedbacks between ecosystem structure and function were designed to make use of the long term experiment.

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II. NETWORK PARTICIPATION AND SYNTHESIS ACTIVITIES

Network Participation

SBC LTER plays a prominent and visible role in the activities and operation of the LTER network. SBC scientists have been actively involved in a number of network-wide committees. Lead PI Dan Reed served as a member on the Executive Board of the LTER Network from 2006-2009 and has been on the Network's three-member Publications Committee since 2005. Associate Investigator Libe Washburn is currently a member of the LTER Network Information Systems Advisory Committee (NISAC) charged with the planning, promoting and evaluating all network information system activities. Education coordinator Ali Whitmer is a co-chair of the LTER Education Committee. Investigator Cristina Tague recently became a site representative to the LTER Climate Committee. Information manager Margaret O'Brien is an active member of the LTER Network Information Management Committee (IMC), and is currently the co-chair. She is involved in several network groups concerned with metadata and data quality.

SBC scientists also played an active role in developing the LTER network's Decadal Plan. Whitmer was a Co-PI on the LTER Network's Planning Grant that funded the activities that led to the formulation of the Decadal Plan. She had the primary responsibility of integrating education and outreach into this process. She and Reed were members of the writing team that produced the Integrated Research Plan. Investigators Melack and Cardinale along with Whitmer and Reed were members of the Conference Committee, which developed the research ideas that formed the basis of the Network's Integrated Research Plan. Melack was also a member of the Research Initiatives Subcommittee that produced "Integrative Science for Society and Environment (ISSE): A Strategic Research Initiative". This document was delivered to NSF on behalf of the LTER Network and represents a unifying framework for studying interactions and feedbacks between humans and the natural world in which they live.

SBC scientists have been frequent participants in the LTER's annual mini-symposiums held at NSF each winter and have given talks in four of the last six symposia on topics ranging from managed lands, long-term research in marine systems, the integration of science and education, ISSE, and ecosystem connectivity. SBC scientists have also been invited to give presentations at several LTER Science Council Meetings, and a large contingent of SBC students and investigators routinely attend the Network's tri-annual LTER All Scientist Meetings.

Synthesis Activities

Synthesis at SBC LTER is achieved in a number of areas using a variety of approaches that include network working groups, cross-site studies, and ongoing collaborations with other projects aimed at broadening the regional context for our results. Below we summarize our major activities and accomplishments in the area of synthesis.

LTER Network working groups

SBC researchers have been active in a variety of cross-site synthesis activities sponsored by the LTER Network. The most recent of these activities involve participation in the EcoTrends project as selected members in the working groups on Biogeochemisty (Melack), NPP-Biodiversity (Reed), and State Change (Holbrook, Schmitt, and Rassweiler). Post doc Rassweiler participated in a working group on species-time relationships that resulted in two cross-site synthesis papers that included SBC data and analyses. Rassweiler also contributed analyses of SBC data on kelp primary production as a co-author of a chapter in the book "Principles and Standards for Measuring Primary Production", which was published by Oxford University Press as part of the US LTER Science and Synthesis Book Series.

Remote sensing and regional population dynamics of giant kelp

With co-funding from NASA, SBC Investigators Siegel, Gaines, Zimmerman and Reed are using a combination of (1) high-resolution remote sensing of giant kelp cover, biomass, and physiological state, (2) metapopulation modeling of patch dynamics, and (3) bio-optical modeling of kelp productivity, to synthesize the ecological processes driving giant kelp dynamics. The goal of this research is to develop a unified regional assessment of the processes controlling giant kelp cover and biomass for the nearshore waters off California from available satellite data. Supplemental funding from NSF's Office of International Science and Engineering was used to provide support for our collaborations with algal geneticists at the University of Algarve (Portugal) to develop genetic markers for giant kelp (Alberto et al. 2009), which we have successfully used to determine the spatial patterns of kelp population connectivity (Alberto et al. *in press*), which is critical to metapopulation modeling of kelp patch dynamics. This work has a multitude of real-world applications including the ecological assessment of marine protected areas that have been recently designated around the Channel Islands National Marine Sanctuary and other California marine protected areas, including the emerging state-mandated network of marine reserves along the California coast.

Cross-site studies involving dissolved organic matter

Associate investigator Carlson is leading a cross-site study between SBC and Moorea Coral Reef (MCR) LTER on the dynamics and distribution patterns of dissolved organic matter and its fate at both sites. The research specifically focuses on factors that control DOM utilization by heterotrophic microbes such as quality of DOM, inorganic nutrient controls and microbial community structure. The sources of fresh DOM are quite different at MCR coral reefs and SBC kelp forests and samples of DOM concentration and chemical characterization at the two sites are being collected for comparison. These collections are being complemented with microbial remineralization experiments to assess difference in DOM availability between the two sites and to determine which microbial consortia are shared and which differ between the sites.

Carlson and colleagues are also participating in the MIRADA LTER project, which is an NSF-funded microbial biodiversity survey and inventory led by Linda Armaral-Zetler (PAL) across all 13 of the major aquatic (marine and freshwater) LTER sites. Carlson's group has contributed microbial DNA samples from Moorea and the Santa Barbara Channel for Tag sequencing runs using 454 pyrosequencing. Results from these analyses are providing much new insight into the similarities and differences in microbial diversity and community structure among the LTER sites.

Collaborations involving oceanographic time series observations

Our oceanographic studies of the Santa Barbara Channel are greatly enhanced by collaborations with other projects. Chief among these is the Plumes and Blooms (PnB) program whose primary research focus is to understand the processes controlling ocean color variability in the Case II waters of the Santa Barbara Channel, and to use that understanding to develop new models for satellite quantification for coastal waters. PnB is supported by NASA, and the Channel Islands National Marine Sanctuary provides monthly one-day, cross-channel cruises on their vessel, the R/V Shearwater. Although the focus of PnB is on informing and validating satellite ocean color observations, the monthly PnB cruises provide valuable time series data on a variety of hydrographic and biological attributes of the Santa Barbara Channel. Additional synergies come by way of collaboration with researchers from the University of South Carolina (B. Thunnel and C. Benetiz-Nelson) who are collecting long-term time series data on particle fluxes using a moored sediment trap array at the center of the Santa Barbara Channel. Data made available through these collaborations have allowed for more in depth synthesis by SBC scientists on a variety of research topics including the toxicity and ecological consequences of blooms of the harmful alga *Pseudo-nitzchia australis,* inorganic carbon

system dynamics and acidification, seasonal changes in the vertical carbon budget using measurements of POC, DOC and DIC concentrations, and patterns and rates of biogenic and lithogenic silica cycling.

Collaborations involving the development of real time environmental sensor networks
SBC LTER investigators have been collaborating with scientists from the MCR LTER site and UC San Diego to develop and test real time environmental sensors for use on marine reefs. In 2007, the Gordon and Betty Moore Foundation funded a large project to build up shared infrastructure of two communities (GLEON for lakes and CREON for coral reefs) to serve as a model of the grass-roots approach to real-time environmental observatories. The goal is to build environmental sensor networks that are driven by science questions that can best be answered at a network scale. One focus has been to develop middleware (primarily using DataTurbine) and tailor it to the instruments typically deployed by the research community (e.g., SeaBird CTDs and Campbell data loggers in the case of MCR and SBC). In the ongoing collaboration for marine sensors, computer scientists from UC San Diego develop software applications for specific instruments. Benchtop testing takes place in San Diego and Santa Barbara followed by ocean deployment at SBC sites, including a test site at Stearns Wharf in Santa Barbara. Ultimately instruments will be deployed offshore on moorings on reefs at SBC and MCR (as well as other reef sites). This intensive development and testing approach involves a weekly conference call for marine scientists, technicians and computer scientists from SBC, MCR and UC San Diego.

Socio-ecological interactions
The Santa Barbara Coastal (SBC) and Moorea Coral Reef (MCR) LTER programs offer an excellent opportunity to examine how fishing, an economically and socially important form of disturbance, influences ecosystem services provided by marine biogenic habitat, specifically giant kelp forests and coral reefs. With supplemental funding from NSF's Directorate for Social, Behavioral and Economic Sciences, Investigators Lenihan and Carr have embarked on a cross-site SBC-MCR study that examines interactions between humans and reef ecosystems, which vary greatly between the two sites with respect to environmental conditions, scales of economic enterprise, social complexity, and management efforts. Research at SBC on this topic has focused on the lobster trap fishery and combines a synthesis of SBC ecological data with fishery log book and socio-economic data to determine (1) the effects of fishing on lobster populations and the effects of environmental change (i.e., kelp loss) on lobster fishing, (2) the factors that affect lobster fishing effort, catch and profits, and (3) impacts of the newly established Channel Islands marine reserves on the catch, profits, and social structure of the lobster fishery.

Development of IM tools for network synthesis
IM manager O'Brien is the lead PI of a LTER Network funded project to develop a project database for LTER sites. Most LTER sites feel the need to document research projects for annual reporting, field site permissions, and coordination of research activities in space and time. However, to accommodate cross-site and network level research activities these documentation systems must be made more flexible and accessible from all involved sites or centrally from the LNO website. Moreover, scientists must be able to browse scientific projects in a consistent format. The O'Brien-led project seeks to develop infrastructure modules to manage the descriptions of scientific research projects based on outlined principles for 'Network Level Information Technology.' It meshes with NISAC's CI Implementation plan, accommodates existing legacy systems and provides a solution to local needs and a basis for extending functionality to implement the above.

Cross-site studies and synthesis in science education

SBC education coordinator Whitmer has played a prominent role in developing and implementing the LTER Network's Education plan. Her leadership and efforts in this area have led to a formidable education and outreach program at SBC, which has become an active area for cross-site synthesis. Of particular note in this regard is a recently funded NSF Math and Science Partnership award (of which Whitmer is a Co-PI) involving four LTER sites (SBC, SGS, KBS, BES) and the LTER Network Office. The project focuses on the critical education juncture of middle school through high school (grades 6-12) and is aimed at developing a program of teacher professional development in science and mathematics that is driven by an environmental science literacy framework that is centered on learning progressions of core science and mathematics concepts coupled with citizenship. The partnership seeks to connect the research prowess in the environmental sciences and education of the LTER sites with teacher professional development in science and mathematics. The focus of this program is on coupled human-natural systems (a major theme of the LTER Decadal Plan) that develops a culturally relevant ecology from both a scientific and educational perspective.

III. INFORMATION MANAGEMENT

The primary objective of the Santa Barbara Coastal LTER Information Management System (IMS) is to facilitate diverse research and outreach goals by focusing on ease of access, data organization and integrity, and long-term preservation. SBC LTER has a dedicated information manager (Margaret O'Brien) with contributions from the project coordinator (Jenny Dugan) and from designated project staff in each research group. Undergraduate students employed as either paid interns or with REU stipends assist with directed tasks. Our personnel also rely on our close collaboration with local IM/IT groups including UCSB's Marine Science Institute (MSI.ucsb.edu), the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCOweb.org), the Moorea Coral Reef LTER (MCR.lternet.edu), the Institute for Computational Earth Systems Science (www.ICESS.ucsb.edu), and the Ecoinformatics program at the National Center for Ecological Analysis and Synthesis (NCEAS.ucsb.edu).

The major hardware and software components are our fileserver and website. Since its inception, SBC LTER's IMS has maintained a stable directory hierarchy that is easily accessible to all SBC LTER users. Any user with a SBC LTER account may view or download a file; however, write-permission is limited to those responsible for data organization and maintenance. With this system, raw data are available to all members immediately. The use of a common directory system also facilitates data publication and eases data exchange between scientific and IM staff. Our website content is organized around broad subject areas including research activities, locale and sampling site, project personnel, data, publications, and education/outreach. Links to all subject areas are on every website page, and the website complies with network standards with regards to menus and links.

A major task of the IM system is data publication. SBC LTER's policy for publication is aligned with the Network's "Type I-II" designations. Our Type I data are generally posted publicly within 2 years of collection, although some ongoing electronic data are available much sooner and other data may be delayed due to time-consuming chemical analyses and data processing procedures. Our policy for "Type II" data is that they will be described in the public catalog, and interested parties are instructed to contact the owner for the data. In addition, SBC LTER employs a "Type 0 (zero)" designation for data that we have acquired from outside parties, which is often already publicly available (e.g., USGS stream flow). These data are usually not republished, but instead, interested parties are redirected to the original data repository. SBC LTER's and the LTER Network's data policies are available on our website. The main top-level data page on the SBC LTER website complies with all network guidelines for content, search and links, including links to the LTER Metacat data catalog, network-wide databases, and the EcoTrends project. Our data catalog is organized to facilitate data discovery. All of SBC's datasets are grouped into collections that are identified as to general content and source (SBC-funded or other project). Collections can be browsed by local habitat, measurement types and LTER Core Research Areas. Additionally, individual datasets can be searched by investigator name or key terms. Because our catalog is based on the network standard, Ecological Metadata Language (EML), local search results are identical to those returned by LTER Network searches.

Development of a metadata-driven system

SBC LTER's information system manages two major resources, datasets and a bibliography of citations, both of which are displayed in local catalogs and shared as needed. Several metadata components (e.g., people, places and projects) are necessary to describe a given data resource. These components also provide the basis for website subject areas (Figure III.1), and continued development of our central metadata system will enable links between the two. SBC LTER's metadata system is based on EML, and we have developed other compatible XML schemas to meet local needs when necessary.

ASCII tables are used for data exchange and archive as they have proven to be the most flexible and efficient for highly varied data. Because these tables can become large and cumbersome as the time series grows, we have developed a generic tool for loading data into a relational database so that it can be queried with web forms generated from its EML metadata (described below). Wherever possible, we make use of shared resources, such as databases, catalogs and code. Our system is not complete; tools are still required to adequately describe and deliver some components. In Figure III.1 the degree to which lines are filled in reflects the degree to which tools are meeting SBC's needs for efficient information exchange between metadata storage and website or datasets. Timely data publication is of high priority, and so metadata documents are created manually in cases where tools are not yet available to generate EML. Documentation for all information management projects can be found in that area of our web site (http://sbc.lternet.edu/info_management).

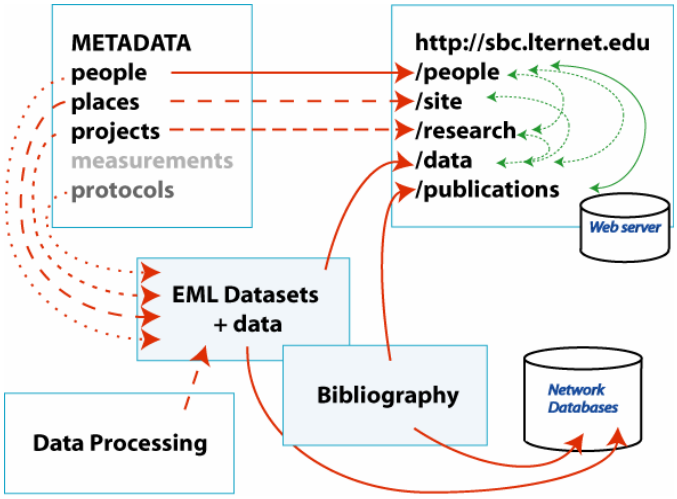

Figure III.1. Information flow in a metadata-driven system. Our two major products are shown in blue boxes. Red lines indicate information flow between components, and green lines are links within the website. Solid lines indicate that data repositories and management tools are adequate. Dashed lines indicate components that are currently in development.

Data organization and publication

As a data provider, SBC LTER has developed a framework to outline the steps of dataset creation in terms of: (1) metadata content, (2) sources and timing of metadata additions, (3) data inclusion, and (4) quality of both metadata and data. These are somewhat analogous to the LTER Network levels for EML metadata completeness (EML Best Practices, 2004), although the network levels do not include metrics for data or metadata quality. It has been our experience that both high-quality data and metadata are paramount if data are to be used in sophisticated applications, and that simply making data available is not enough. Our policy is to publish a dataset only when data are available. Published datasets are of two levels (Download & Integration), whose general features and potential uses are shown in Table III.1 (a complete description of the data framework can be found on our website at http://sbc.lternet.edu/info_management/). The primary difference between the two levels of datasets is that substantially more effort is required to produce an "Integration" level dataset from which the data can be accessed by an application using only the EML metadata, for example, ingestion into a relational database. Approximately 40% of SBC LTER's data holdings are at "Integration" level. We are also planning for the incorporation of more advanced features that will further enable streamlined discovery and use, such as semantic annotation, unique and consistent identifiers, detailed methods and sampling design in metadata markup, and quality-controlled data values. However, adding these features requires the development of more sophisticated tools than are currently available, and will be most effective to implement after significant standardization has occurred at the LTER Network level.

Table III.1. Features of SBC LTER data products with their potential uses

Level	Features	Potential uses
Download	Metadata**:** - At least one data table - Access and policies stated Data: - Poor data formats are allowed	- Data can be downloaded, although a user may have questions about content and formats.
Integration	Metadata: - Application dependent, e.g., for upload to SBC's query application, sampling sites are required Data: - Clean formats - Data matches metadata	- Integrate data using metadata - Query applications - Contribute to Network databases

SBC LTER datasets are co-managed by Information Manager O'Brien and the data owners (SBC investigators and their research staff). Co-management is especially important for datasets that are designated as "ongoing" since scientific personnel are the best source for knowledge about changes to sampling protocols and data output. This management style requires coordination among diverse scientific domains, measurement types, processing patterns and software choices, and also must accommodate both long-term and short-term collections. It requires communication and training of scientific staff in the use of editors (e.g., Morpho), formats (XML), informatics concepts (e.g., SI units), programming practices, and our shared file server, while not placing them under undue burden.

Coordinated data publication can be illustrated by our process for publishing electronic data using Matlab. The example in Figure III.2 describes processing of our stream discharge data, but the same sequence is used for sensor data from moored oceanographic instruments. Data are processed in the laboratory as appropriate. An output format for the table is agreed upon by the data owners and the information manager. The information manager creates an EML metadata template, which is filled in using semi-customized export scripts written in Matlab, by either the data owners or the information manager. The export script can include a step to upload to the data catalog. Using the same scripting language that is used for data processing (in this case, Matlab) means that data publication can be more easily integrated with processing. The entire process has the advantage of furnishing a standard dataset that can also be used as input for value-added products - in this case, as input for a script that produces a file for the network database, ClimDB, in its required format – a task which is typically the responsibility of an information manager. Structured metadata

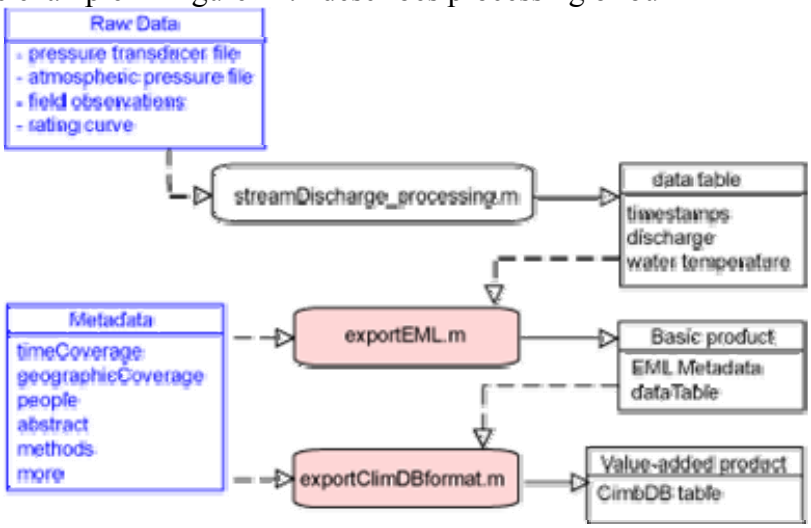

Figure III.1. Data processing flow for SBC LTER's stream discharge data. Components contributed by the IM team are in pink boxes. Data inputs are in blue, and data products are on the right.

in a centralized location facilitates the production of datasets via scripts, and also becomes available for multiple uses; e.g., metadata could be incorporated earlier in processing.

Our data organization also facilitates incorporation into our EML dataset query tool (Figure III.3). This tool is a generic application that reads EML metadata, inserts the data table into a relational database and creates a map interface and form so that a user may subset large data products. The application takes advantage of established community standards and accommodates a variety of data tables. Currently, about 30% of SBC LTER's data can be accessed through this interface, and incorporation depends mainly on the level of data and metadata quality and on the style and/or availability of geo-located observations.

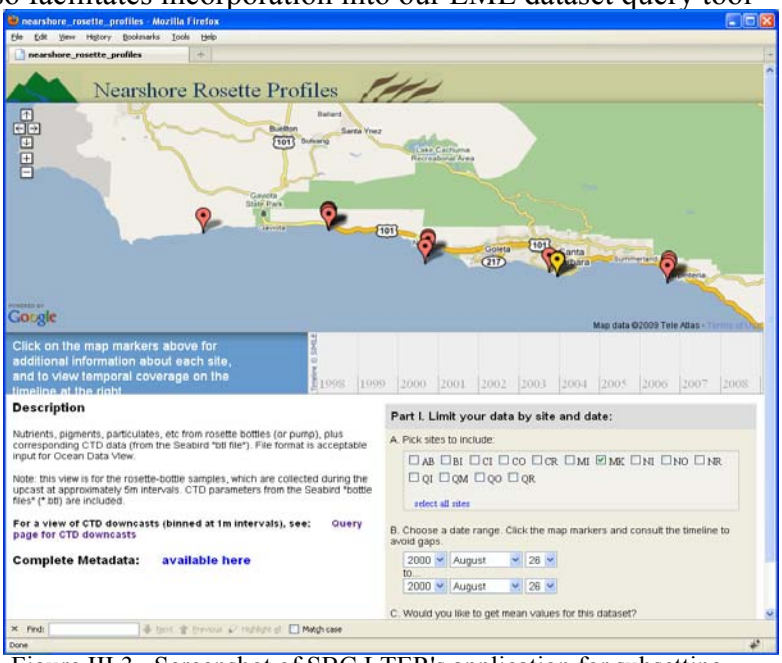

Figure III.3. Screenshot of SBC LTER's application for subsetting data. The map markers and forms are generated by EML metadata.

IV. SITE MANAGEMENT

Governance

The research management plan for the Santa Barbara Coastal LTER program encompasses several important focal areas, including internal project governance, project resource allocation and acquisition, day-to-day running of the project, site plan and preservation, agency relations (including NSF) and interactions with the LTER network of sites. Our project is governed openly by PI Reed and Co-PIs Gaines, Holbrook, Melack, and Siegel, which has proved to be both effective and efficient. All major issues pertaining to the project's research direction, strategic planning, resource allocation, administrative policies, and staffing are discussed at meetings held on an as needed basis that are open to all SBC investigators and IM manager O'Brien. General discussion is taken into consideration and decisions are generally reached by consensus of all interested parties. The meetings typically include progress reports of ongoing research and education activities and serve to keep everyone informed of the project's broad range of activities, which aids in coordination and integration of the different project components.

Project management

Day to day management of the project is overseen by PI Reed with assistance from 50% time Project Coordinator Dugan. Management activities include: (1) coordinating the activities of different research groups to maximize efficiency and integration, (2) working with the Outreach Coordinator Whitmer and SBC investigators to integrate the project's research and education activities, (3) facilitating the transfer of data and other information from project personnel to the SBC Information Manager O'Brien, (4) responding to inquiries and requests from the LTER Network and non-LTER entities, (5) scheduling and planning project meetings and events, (6) preparing project-related reports and proposals, and (7) serving as the site representative at meetings and functions on and off campus. Fund allocation is structured around long-term studies associated with the primary research biomes (watershed, kelp forest, offshore ocean) with a lead investigator(s) assigned to each biome. Additional funds are provided to investigators of shorter-term (1-3 years) research campaigns that target specific questions identified in the project's conceptual framework. A separate allotment of funds is set aside to cover the costs of project management, information management, and core long-term measurements.

Information exchange and collaborations

The coordination of research and the exchange of information and ideas are facilitated by the fact that 20 of our 25 investigators are located at UCSB. Informal and scheduled meetings involving investigators, post docs, students and staff to discuss project related business occur on a daily basis. The sharing of data, documents, and other project-related products is made easy through our central data server which all participants (UCSB and non-UCSB) have access to (see Section III - Information Management).

In addition to our scheduled meetings, we hold an annual retreat for all SBC LTER participants and other interested parties to insure coordination across the SBC LTER program and to enhance interdisciplinary discussions. This event has been well attended in the past and has served as an excellent venue for information exchange and team building.

Unlike several other LTER sites, SBC LTER does not have a formal agreement with a federal agency or non-governmental organization that facilitates collaborations and provides research support. Instead, we have relied upon the long-term nature of LTER support and the temporally and spatially comprehensive data that it generates to serve as a platform for attracting collaborations with other extramurally funded projects. We have

been very successful in this regard, attracting funds from a variety of federal, state, local, and private sources, many for collaborative research projects with non-LTER investigators. Several of these non-LTER collaborators have since established formal associations with SBC (e.g., Alberto, Carlson, Dudley, Gaylord, Lenihan, MacIntyre, Zimmerman).

Planning for the future

Planning for a long-term project like an LTER site requires a strategy for replacing expertise in research areas vacated by scientists that have left the project and for adding expertise in areas of new research initiatives. The addition of new Associate Investigators is accomplished either by active recruitment to fill a specific research need, or via invitation to collaborating scientists who are interested in becoming formally associated with the project. In both cases the addition of new investigators is determined by consensus of the Executive Committee with input from all Associate Investigators. Eleven of SBC LTER's 20 Associate Investigators have been added to our project since our initial proposal was funded in 2000. These additions include individuals from four institutions other than UCSB (Moss Landing Marine Laboratories, Old Dominion University, UC Davis, and San Diego State University). Most of these additions have been of early career scientists who offer a potential for a long-term commitment to the project.

V. EDUCATION, OUTREACH AND OTHER BROADER IMPACTS

Education and Outreach

Schoolyard LTER (SLTER)

A major goal of our Schoolyard program is to instill a strong appreciation for stewardship of coastal land and marine habitats. We do this by working with students and teachers in middle and high schools. We also partner and leverage other projects that include student and teacher outreach, such as our recently funded Math Science Partnership project (see below). SBC's SLTER program is organized around a theme of watershed ecology. This approach allows for an integrated land-ocean focused program that includes students, teachers, undergraduate and graduate students. In 2009 we focused on developing a partnership with the American Association of University Women's (AAUW) *Tech Trek Program***.** Tech Trek is a math/science summer camp designed to develop interest, excitement and self-confidence in young women who will enter eighth grade in the fall. This residential program features hands-on activities in math, science and related fields. Our SBC SLTER program developed and implemented lesson plans to approximately 60 middle school girls that focused on kelp forests and coastal conservation. The program took place in university teaching labs, in our educational aquarium facility, and on board a 75' catamaran.

One of the hallmarks of our SLTER program is the work done by undergraduate docents in our educational aquarium, *The REEF* (Research Experience and Education Facility). The REEF hosts thousands of school aged children and their families and teachers each year. The SLTER supports the development of lesson plans and activities provided at The REEF throughout the year. Undergraduate students enroll in our science pedagogy course (taught by an SBC LTER educator) to learn about learning theory and effective pedagogical practices. They use these skills in our REEF program as well as with our *Mobile REEF*, a specially outfitted van used to transport docents and animals to classrooms for schools that can not visit our aquarium.

Math Science Partnership (MSP) Program

SBC LTER's Math-Science Partnership Program is a new NSF-funded project that connects the research and education prowess in the environmental sciences of universities and the LTER Network with the professional development of science teachers of partner middle schools and high schools. The project involves four LTER research sites (SBC, SGS, KBS, BES) and 22 K-12 schools/districts that extend across the nation, and directly impacts over 250 science teachers and up to 70,000 students of highly diverse backgrounds. The program focuses on coupled human-ecosystem interactions in the context of socio-ecological systems as a framework to develop a culturally relevant ecology from both a scientific and educational perspective.

Two 3-day inaugural workshops on targeted partnerships in math and science were held at SBC LTER in July and August 2009. These targeted partnerships focus on the critical education junction of middle school through high school to develop a program of teacher professional development in science and mathematics driven by framework of environmental science literacy surrounding the learning progressions of core science concepts. In our first workshop, middle school teachers were introduced to SBC LTER research through a day-long field trip of the biomes, study sites and research laboratories. Initial discussions of program goals and evaluation strategies were combined with demonstrations and critiques of existing lesson plans previously developed through SLTER efforts, and opportunities for incorporating SBC LTER datasets into lesson plans and activities in the classroom.

The second workshop took place at a local middle school where SBC LTER researchers and students learned about the logistics of developing a middle school science curriculum, the circumstances under which students and teachers work, and the ways in

which SBC LTER can partner to improve middle school science education. This workshop also provided an opportunity for teachers and graduate student fellows to talk about how they could work together in the classroom to promote science learning and careers. Currently, two graduate student fellows are working with our 3 lead teachers in a GK12-like model partnership.

Training and development

Education and training are tightly integrated into all aspects of SBC LTER research. As of August 2009 10 post docs, 37 graduate students, 8 REU students and more than 100 undergraduate students have participated in research funded by our current award. SBC LTER provides research training opportunities to more than 25 undergraduate students each year. In addition to gaining valuable research experience, many of the undergraduate students earn academic credit or receive monetary compensation for participating in SBC research as interns and honors students. SBC LTER investigators, graduate students and staff mentor independent research by undergraduates and local high school students. SBC LTER is an active participant in NSF's Research Experience for Undergraduates program and in several other mentorship programs sponsored by the University of California. REU students work closely with SBC researchers on both core measurements and experimental studies in the kelp forest. Our project's research regularly finds its way into the classroom as SBC investigators routinely incorporate activities and findings of SBC-sponsored research into their teaching, thereby extending the project's contributions to the broader student body. Many SBC investigators give guest lectures and class demonstrations on SBC research in university courses.

SBC LTER hosted the fall Ecological Society of America SEEDS field trip in 2007 with support by a special supplemental grant from NSF. ESA's SEEDS program mission is to diversify and advance the profession of ecology through opportunities that stimulate and nurture the interest and involvement of underrepresented students (http://www.esa.org/seeds/). The field trip featured a visit to the SBC LTER kelp forest and research divers at Mohawk Reef aboard the R/V Cormorant, a guided tour of Santa Barbara's working harbor, meeting with a Native American Chumash elder at the Santa Barbara Maritime Museum, a visit to UCSB's REEF, rocky intertidal and beach monitoring activities at Campus Point and a tour of SBC watersheds. A dinner with SBC LTER graduate students and faculty investigators fostered one on one discussion. The students posted a report and photos about their experiences on the SBC field trip (website: http://www.esa.org/seeds/).

SBC LTER graduate student and postdoctoral training is integrated with a variety of other programs on the UCSB campus including the Donald Bren School of Environmental Science and Management, The Institute for Computational Earth System Science, the Interdepartmental Marine Science Program, and the Partnership for Interdisciplinary Studies of the Coastal Ocean. With the SBC LTER, these programs promote interdisciplinary research to examine how coastal ecosystems change in response to natural and human-induced alterations in the environment. SBC training includes students and post docs working in terrestrial, aquatic, and marine environments with interests ranging across ecology, physiology, geology, hydrology, oceanography, modeling and coastal policy. This enables valuable cross-training on environmental issues pertaining to coastal ecosystems, provides a common language for communicating scientific information on these issues, and contributes to the creation of a diverse scientific community of students and post docs that fosters a respect and appreciation for other disciplines. SBC students, postdoctoral fellows, and investigators participated in the SBC LTER Spring Science Meetings in 2007 and 2008. At these meetings, results from SBC LTER research and collaborative projects were presented in an interactive poster session, and oral presentations. SBC graduate students also participated in the first UC-LTER graduate - post doc symposium organized by the CCE LTER in May 2008.

Educational opportunities at SBC LTER are not limited to university students and post docs. Teachers and numerous volunteers from the general public regularly participate in our stream sampling program and gain considerable knowledge about the constituents of runoff and the processes that influence their concentrations.

Broader impacts

The broader impacts of SBC LTER research manifest across local, regional and national scales. SBC LTER investigators continue to be very active in sharing and applying SBC results and their knowledge of Santa Barbara's coastal ecosystems and to address changes in local and regional policies. SBC LTER investigators serve as advisors and committee and board members for a number of local and national groups concerned with conservation and management of natural resources and apply the results of SBC LTER research to these topics.

Conservation and Marine Protected Areas

The process of establishing a network of marine reserves in California is ongoing through the Marine Life Protection Act. SBC investigators continue to play an important and active role working with state and federal agencies on these issues. CoPI Gaines is a member of the state-wide Master Planning Team and the science advisory team for the California Marine Life Protection Act. He also serves on several committees and advisory groups concerned with fisheries and marine conservation including the Science Advisory Group for the Interagency Ecological Program of the California Department of Water Resources, the Marine Life Protection Act Baseline Science Management Panel and the Joint Ocean Commission. Associate Investigator Lenihan has been working collaboratively with local fisheries, fishery management agencies and SBC LTER to quantify the effects of existing marine reserves at the Channel Islands and at soon to be established marine reserves along the mainland coast of the Santa Barbara Channel on populations of target species, the economic performance of the fisheries, and the social structure of the fishing communities (www.calobster.org). A major focus of this research is to develop management models that use marine reserves in spatially-explicit, collaborative fishery management strategies. A number of other SBC investigators are actively working with the Science Advisory Panel and stakeholder groups using SBC data and results to provide information needed to develop the regional profile and evaluate proposals for reserve network design for the south coast region.

Ecological restoration

Investigators Reed and Page work with the staff of the California Coastal Commission (CCC) on a large multi-dimensional program designed to mitigate for the loss of coastal marine resources caused by the operation of the San Onofre Nuclear Generating Station (SONGS), a coastal power plant located in north San Diego County. The major emphasis in this program is compensation for lost marine resources via wetland and kelp forest restoration. Reed and Page's primary responsibilities are to consult with the employees of the power plant (Southern California Edison), the CCC and their staff, and other resource agencies on ecological issues relating to the design of the mitigation projects and to develop and implement monitoring programs capable of determining whether the biological and physical performance of these projects meet pre-determined standards. Much of the science done on these mitigation projects is quite complementary to that done by SBC LTER and there is considerable exchange of information and ideas between the two projects.

Water quality and watershed management

SBC LTER research plays an important role in informing and shaping policy directed at local watershed issues. We have developed and maintained mutually beneficial,

cooperative associations with local government departments and NGOs concerned with watersheds and water quality. Santa Barbara County's Project Clean Water and the City of Santa Barbara are engaged in sampling local creeks and measuring a suite of pollutants including metals, pesticides and herbicides. Our intensive sampling of nutrients and particulates during the entire hydrograph for most storms complements the County's and City's efforts, and data and interpretations are mutually shared. The Santa Barbara Channel Keepers conduct monthly collections along the Ventura River and on several creeks in the Goleta area, and we perform analyses of nutrients on their samples. Co-PI Melack serves on the Technical Advisory Committee for Friends of Santa Clara River water quality monitoring program as well as on national committees concerned with water quality and methodology.

Fire impacts to Santa Barbara watersheds and streams

Three major fires have occurred in the Santa Barbara area since summer 2008 (the Gap Fire in July 2008, the Tea Fire in November 2008 and the Jesusita Fire in May 2009), resulting in large scale evacuations of residents and the loss of nearly 300 homes. The total acreage burned in less than one year in these three fires was 8140 ha located in and above the cities of Santa Barbara, Montecito and Goleta. SBC collects data that will help evaluate the effects of these 3 major fires on the composition of runoff and stream discharge in a variety of catchments. SBC LTER investigators Cooper and Melack are working with NGO, county and federal agencies to document effects of the fires and contribute to planning and preparation for post fire impacts. A larger group of SBC LTER investigators are building collaborations and pursuing support for more intensive studies of the burned catchments and the implications for runoff and coastal impacts.

Beach conservation and management

The conservation and management of sandy beach ecosystems lags behind that of coastal wetlands and riparian habitats. SBC LTER research on kelp wrack in these ecosystems has led to the recognition of wrack as an ecological resource by local and state agencies and contributed to the development of new policies for coastal management. SBC LTER investigators Dugan and Page are working with California State Parks to develop and evaluate new restoration strategies for wrack-associated invertebrates on beaches that support breeding snowy plovers, a federally listed shorebird. Dugan plays an active advisory role to coastal consortiums and groups concerned with improving the conservation and management of beach ecosystems. She is a member of the Beach Ecology Coalition, a new professional organization for beach managers that provides a forum for education, outreach, training and development of best practices and cooperative research on sandy beach ecosystems in California.

VI. PROFILES OF SBC LTER PARTICIPANTS

more information on SBC LTER participants can be found at:
http://sbc.lternet.edu//cgi-bin/ldapweb2006.cgi

Investigators

Filipe Alberto

Research Fellow, CCMAR, CIMAR-Laboratório Associado, Faculdade de Ciencias do Mar e Ambiente (F.C.M.A.), Universidade do Algarve , Campus de Gambelas, P-8005-139, Faro, Portugal

Research Interests: population genetics of marine macrophytes

Role in SBC LTER: Associate Investigator

My research is part of an ongoing collaboration aimed at using molecular ecology to study giant kelp forests at local, regional and global scales. SBC LTER's long-term investigations of the processes affecting the dynamics of giant kelp forests distributed throughout the Santa Barbara Channel allow us to contrast results of population genetics with the continuous body of data and hypotheses driven by lengthy time-series data. With co-funding from FCT (Portuguese Science Foundation) we isolated microsatellite markers from giant kelp, which we are using to estimate the genetic connectivity among kelp forests within the SBC LTER region. We are also using these genetic markers to investigate several hypotheses concerning biogeography, population dynamics and reproductive biology.

Edward Beighley

Associate Professor, Department of Civil, Construction, and Environmental Engineering, San Diego State University, San Diego, CA. 92182-1324

Research Interests: Hydrological modeling, soil erosion, spatial data analysis

Role in SBC LTER: Associate Investigator

I am involved in the terrestrial export of water, nutrients and sediments to the ocean. I am chiefly responsible for continued development of the terrestrial runoff modeling effort. This includes the integration of SBC LTER in-situ measurements (rainfall and streamflow) and remote sensing products (e.g., NASA satellite data for landcover, LAI, albedo, air temperature, precipitation); revision/addition of physical processes into the modeling framework; characterization of potential climate and land use change scenarios; quantifying the terrestrial runoff characteristics for past, current and future climate and land use patterns.

Mark Brzezinski

Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Phytoplankton ecology and physiology; phytoplankton cell cycles; elemental cycling in surface ocean

Role in SBC LTER: Associate Investigator

I am chiefly responsible for the monthly monitoring of water chemistry at the core kelp forests sites. I am also a participant in four of the shorter-term process studies involving i) the analysis of oceanographic data from the 16 basin wide oceanographic surveys conducted from 2001-2006 to access mechanisms controlling the distribution of phytoplankton productivity and the relationship between currents and the delivery of subsidies (dissolved and particulate) to the continental shelf, ii) the partitioning of net primary production among giant kelp, understory algae and phytoplankton within kelp forests, iii) interactions between the kelp forest and its flow environment with regards to the delivery and utilization of nutrients, and iv) the connectivity between kelp forests and offshore waters as influenced by processes influencing the exchange of materials across the continental shelf.

Brad Cardinale
Assistant Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Community and ecosystems ecology, freshwater biology, biodiversity and ecosystem functioning.
Role in SBC LTER: Associate Investigator
My role in the SBC LTER is to help resolve a paradox that has plagued ecologists for decades. On one hand, classic ecological theory argues that the diversity of species in an ecosystem is limited by the productivity of that system. On the other hand, modern experiments have shown that the productivity of an ecosystem is the direct product of species diversity. How can biological diversity simultaneously be a cause as well as a consequence of ecosystem production? I am leading manipulative experiments in streams and kelp beds that will characterize how species diversity and productivity can simultaneously feedback to influence one another in space and time.

Craig Carlson
Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Marine microbial ecology, bacterioplankton, dissolved organic carbon, marine biogeochemistry.
Role in SBC LTER: Associate Investigator
My research focuses on the interaction between microbial processes and dissolved organic matter in marine systems. The SBC LTER reaches across a large gradient of inorganic and organic nutrients and productivity and is an ideal location to investigate the sources and fate of organic matter and how its quality both affects and is affected by microbial community composition and associated processes. I have participated in several of the oceanographic cruises, have studied rates of DOC production by giant kelp and am currently a Co- investigator (w/ Brzezinski) on the Cross Shelf Time Series campaign that seeks to resolve the development of temporal and spatial gradients in organic and inorganic nutrients in the near shore environment and to determine if those gradients are related to microbial activity and resulting community structure.

David Carr
Assistant Professor, Department of Geography, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Human dimensions of global environmental change, land use/cover change, human migration, fertility, and health
Role in SBC LTER: Associate Investigator
My research with SBC LTER focuses on how humans impact coastal marine ecosystems, and the adaptations of humans to environmental change in these systems. In this capacity I am co-leading (H. Lenihan) a cross-site study with MCR LTER that investigates how fishing, an economically and socially important form of disturbance, influences ecosystem services provided by giant kelp forests and coral reefs. The study, which is being supported by a supplement from NSF's SBE program, examines human-reef interactions under a wide range of environmental conditions and vastly different scales of economic enterprise, social complexity, and management efforts.

Scott Cooper
Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Freshwater biology; stream ecology
Role in SBC LTER: Associate Investigator

My research group and I study the impacts of land use changes, point source pollution, climate change, exotic species, and fire on stream and river communities in southern California. More specifically, our research examines relationships between land use patterns and algal biomass and invertebrate community structure, algal responses to the addition of nutrients, long-term relationships between hydrological conditions and invertebrate assemblages, the effects of exotic crayfish and mud snails on stream communities, and comparisons of stream communities in basins affected and unaffected by wildfires. Our investigations have been underpinned by food web investigations, including field experiments and observations on the effects of native trout and invertebrate predators on lower trophic levels and on the effects of grazers and disturbance on algal assemblages, as well as stable isotope analyses of stream food web structure through the seasons. We interact closely with, and often advise, personnel from local, regional, state, and federal agencies on issues related to stream and river ecology.

Tom Dudley

Associate Research Biologist, Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Stream ecology, invasive species, habitat restoration

Role in SBC LTER: Associate Investigator

My research focuses on streams and rivers, and the biological drivers that influence the transport of organic and inorganic material from watersheds to estuarine and near-shore environments. I am particularly interested in the role of invasive riparian plants in modifying stream channel stability as it relates to altering erosion and sedimentation storage and export. Management to reduce the impacts of invasive plants, including manipulated herbivory (biological control) can alter export of coarse organic material, as well as changing the role of riparian vegetation as a buffer to nutrient transport from uplands into the Santa Barbara Channel. To this end we are developing the use of specialist parasites for biocontrol of invasive freshwater molluscs. This work has direct implications for the biology of sensitive species, particularly southern steelhead as well as various riparian-dependent wildlife species. In addition, I initiated a 5-year development plan for a University of California research station to be situated on the Santa Clara River, which marks the eastern boundary of the SBC LTER. This station will provide a base of operations for watershed-related research projects associated with SBC LTER and other UC programs.

Jenifer Dugan

Associate Research Biologist, Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Coastal ecology and food webs, sandy beaches

Role in SBC LTER: Associate Investigator, Project Coordinator

My SBC research focuses on the fate, processing, and ecological effects of organic subsidies exported from kelp forests to sandy beach ecosystems. I am responsible for the core monitoring of kelp wrack abundance on SBC sandy beaches and am particularly interested in the responses of beach communities and higher trophic levels to spatial and temporal variation in these subsidies. I am also interested in investigating the role of upper intertidal invertebrate consumers in the processing of kelp wrack and the remineralization of nutrients from this source in intertidal porewater.

William Freudenburg

Professor, Environmental Studies Program, University of California, Santa Barbara, CA 93106-4160

Research Interests: resource-dependent communities, social impacts of environmental and technological change, risk analysis
Role in SBC LTER: Associate Investigator
My research focuses on the sociology of coupled human natural systems and within the SBC LTER I provide a voice on issues that pertain to this topic. I have participated in several LTER All Scientists meetings and have been active in working within the LTER Network to develop research projects that fit within its initiative on Integrated Science for Society and the Environment. Currently I am collaborating with SBC LTER investigators on their efforts to document the ecological and socio-economic impacts of the recent fires that have burned much of the Santa Barbara foothills.

Steve Gaines
Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Marine conservation, Biogeography, Effects of climate change on coastal ecosystems, Effects of ocean circulation on dispersal, Sustainable Fisheries
Role in SBC LTER: Co-Principal Investigator
I help coordinate linkages between the work of the SBC LTER and larger regional scale programs such as PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans). These studies place the intensive, long term studies of kelp forest ecosystems in the Santa Barbara Channel in a broader biogeographic context. These efforts have led to characterization of the dynamics of the giant kelp Macrocystis across its entire range and studies of the scales of connectivity between ecosystems via larval dispersal. I also examine the science policy interface to explore the consequences of findings of the SBC LTER for the design of marine protected area networks being implemented along the coast of California.

Brian Gaylord
Associate Professor, Bodega Marine Laboratory, P.O. Box 247, 2099 Westshore Road, Bodega Bay, CA, USA, 94923
Research Interests: Coastal hydrodynamics, functional ecology and biomechanics of marine organisms, larval and spore dispersal ocean acidification,
Role in SBC LTER: Associate Investigator
My research in the SBC focuses on interactions and feedbacks between the kelp forest and its flow environment. Components of this work involve fluxes of material into and around kelp beds, and modeling and measuring spore dispersal to develop estimates of population connectivity among forests, and levels of inbreeding within them.

Anita Guerrini
Professor, History Department, Oregon State University, Corvallis, OR USA 97331
Research Interests: Interactions between animals and human society in history, Role of history in ecological restoration
Role in SBC LTER: Associate Investigator
My main research focus with the SBC LTER is on the role of history in ecological restoration in the coastal zone. To this end I have been working with Jenny Dugan on the ecological history of the Coal Oil Point area on the west campus of UCSB. My particular interest is in exploiting a variety of historical materials (e.g., maps, photos, print and manuscript documents) to find out about past and current human impacts and hopefully inform discussions of restoration and resilience. I'm also interested in policies concerning endangered species.

Sally Holbrook

Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Community ecology; marine vertebrate predation and competition

Role in SBC LTER: Co-Principal Investigator

My students and I conduct studies of kelp forest community ecology, with a particular emphasis on the effects of physical disturbances and biotic interactions on community structure. I am particularly interested in the effects of habitat structure on species interactions. I am also coordinating efforts to bring real-time marine environmental sensing to the project. This is a collaborative project between the Moorea Coral Reef LTER (of which I am a Co-PI), the SBC LTER and UC San Diego, along with international partners in Australia and Taiwan. Initial deployments of key instrumentation have been made at the SBC site (at Stearns Wharf).

Hunter Lenihan

Associate Professor, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Applied marine ecology, fisheries management, social-ecological interactions of marine resource use

Role in SBC LTER: Associate Investigator

My students and I conduct research in fisheries biology, ecology and management in partnership with Santa Barbara Channel fishermen, environmental NGOs, the CA Department of Fish and Game, NOAA-National Marine Fisheries, NOAA-National Marine Sanctuary Program, and the SBC LTER. We are generating and testing theories and methods for the sustainable harvest of rocky reef fish and invertebrates (primarily lobster and abalone) in the Southern California Bight. Our current efforts focus on marine reserves and the development of ecological and socio-economic models of fishery management. We collaborate with fishermen, SBC LTER and other partners to collect socio-economic data, fisheries independent data inside and outside of reserves, and fishery dependent data from ship-board and port sampling collected outside of reserves.

Sally MacIntyre

Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Limnology, coastal oceanography, biogeochemical responses to physical processes

Role in SBC LTER: Associate Investigator

I've contributed to time series and process studies of interactions between the kelp forest and its flow environment with regards to the delivery and utilization of nutrients and will jointly lead studies of the pathways of incoming streams and delivery of subsidies to kelp and other organisms in the nearshore environment.

John Melack

Professor, Department of Ecology, Evolution and Marine Biology and the Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Limnology; hydrology; watershed science; biogeochemistry; wetland ecology; remote sensing.

Role in SBC LTER: Co-Principal Investigator.

I have led the hydrological and hydrochemical measurement and modeling aspects of the SBC LTER. This research has involved installation and operation of stream gauging system and automatic rain gauges, intensive sampling for solutes, and processing and analysis of thousands of water and particulate samples. These data are incorporated

into mechanistic and statistical models of runoff and export, and are included in examination of nutrient supply to the near-shore kelp ecosystem.

Roger Nisbet
Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: Theoretical ecology; population dynamics; dynamic energy budget theory.
Role in SBC LTER: Associate Investigator
I provide advice on theory and modeling to a number of SBC LTER participants, and serve on PhD committees for students performing SBC-related research. One key theme of my work to date has been theory relating to phase shifts in community structure using giant kelp forests of SBC LTER and coral reefs of MCR LTER as study systems.

Margaret O'Brien
Specialist, Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.
Role in SBC LTER: Information Manager
As SBC's Information Manager I am responsible for coordinating and implementing most aspects of data exchange and publication within and outside the group. This includes managing user accounts and services; designing databases, websites and applications; and working with scientists and their staff to plan and publish data products.

Mark Page
Associate Research Biologist, Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: coastal ecology, food web structure and dynamics
Role in SBC LTER: Associate Investigator
I am leading the research effort on studies that use stable isotope techniques to explore the sources of organic matter used by kelp forest consumers. I am particularly interested in quantifying the role of giant kelp in the reef food web and in linkages between land-derived materials and reef producers and consumers.

Dan Reed
Research Biologist, Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.
Research Interests: reef ecology, dispersal and connectivity, primary production of marine macrophytes,
Role in SBC LTER: Lead Principal Investigator.
I am chiefly responsible for the design and maintenance SBC LTER's long-term studies pertaining to kelp forest structure and function. These studies include annual kelp forest community dynamics, monthly production, biomass, and stoichiometry of giant kelp, and the recently initiated long-term experiment on ecosystem responses to annual kelp loss. I also actively participate in a number of SBC LTER's shorter-term process studies and experiments including the partitioning of NPP among kelp forest autotrophs, interactions between the kelp forest and its flow environment, effects of wave disturbance on foodweb structure, gene flow and connectivity in kelp populations, and feedbacks between kelp forest structure and function.

Joshua Schimel
Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Soil ecology; microbial controls of ecosystem processes; terrestrial biogeochemistry.

Role in SBC LTER: Associate Investigator

My research focuses on understanding nutrient dynamics in soil, including analyzing processes that regulate nutrient release and movement into ground and surface waters. Within the SBC LTER, I work with the watershed team to investigate patterns and mechanisms affecting nutrient transport to the coastal ocean and the processing and release of kelp-derived nitrogen in sediments of intertidal beaches.

Russell Schmitt

Professor, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Population and community ecology; applied ecology; consumer-resource interactions; marine invertebrates and reef fishes.

Role in SBC LTER: Associate Investigator

I am a population ecologist interested in consumer – resource interactions and the dynamics of demographically open populations of benthic marine fishes and invertebrates. One of my principal functions in the SBC LTER is to oversee the Santa Cruz Island long-term time series component, initiated in 1982, on the dynamics of surfperch populations, their invertebrate food and the benthic substrata upon which the fish feed. I also am involved in cross-site collaborations with the Moorea Coral Reef LTER (of which I am Lead PI), including a comparison of the responses of fishes to fluctuations in abundance the major foundation taxa in each ecosystem (giant kelp, hard corals).

David Siegel

Professor, Department of Geography, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Coupling of physical, biological, and biogeochemical marine processes on micro to ocean basin scales. Specifically, ocean color remote sensing and optical oceanography, mesoscale and coastal bio-physical interactions, climate change and its impacts, fishery oceanography, numerical modeling and Lagrangian approaches.

Role in SBC LTER: Co-Principal Investigator

My primary role in the SBC LTER is to assess regional kelp cover and biomass using high spatial resolution (10 to 30 m) satellite imagery (SPOT and Landsat) and to provide access, interpretation and analysis of data on ocean color remote sensing and optical oceanography. These observations are providing SBC LTER with a regional perspective on time scales from months to decades. I am also the Lead PI of the NASA funded Plumes and Blooms (PnB) project whose goal is to understand the land and ocean processes changing ocean color. Relevant for the SBC LTER, PnB makes monthly transect surveys across the Santa Barbara Channel of hydrographic, optical and biological parameters.

Christina Tague

Assistant Professor, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: interactions between hydrology and ecosystem processes , climate and land use change.

Role in SBC LTER: Associate Investigator

My research focuses on the development and application of spatial process-based models of terrestrial carbon, water and nutrient cycling. Current investigations use SBC LTER monitoring of stream flow and stream chemistry as well as remote sensing analysis of terrestrial vegetation and land use to improve the parameterization of

coupled eco-hydrologic models. My group is particularly interested in using these models to investigate how fine-scale heterogeneity in urban, agricultural and chapparal dominated systems influence watershed scale fluxes into the coastal zone. Improving our capability to model these systems also contributes to SBC LTER's analyses of the impacts of fire, landuse change and climate warming on water resources and ecosystem services in semi-arid coastal environments.

Libe Washburn

Professor, Department of Geography, University of California, Santa Barbara, CA, USA, 93106.

Research Interests: Coastal circulation, mesoscale processes, air-sea interaction, and interdisciplinary oceanography

Role in SBC LTER: Associate Investigator

I am responsible for directing the physical oceanographic monitoring effort at the core sites in kelp forests. I also coordinate much of the analysis and synthesis of oceanographic data obtained from a series of cruises during 2000-2006 and from moorings at the core sites from 2000 to the present. My research group operates an extensive array of high frequency radars for mapping surface currents in the coastal ocean encompassing all of the field sites within the SBC LTER. Data from the array are important for identifying the spatial structure of currents causing transport through kelp forests at the core sites. A key objective of these efforts is to understand the role of ocean transport processes in the delivery of nutrients, biogenic particles, and other ecologically important waterborne materials to kelp forests on the inner shelf. In collaboration with a group from UC San Diego and the Moorea Coral Reef LTER, I am working to establish real time data nodes in the program and our first installation is on the Stearns Wharf in Santa Barbara.

Ali Whitmer

Assistant Dean of Sciences, Georgetown College, Georgetown University, Washington, DC 20057-1003

Research Interests: population genetics of marine algae, science education and outreach,

Role in SBC LTER: Associate Investigator, Education/Outreach Coordinator

As the Education/Outreach Coordinator I work with SBC scientists, staff, and students in various K-12 and public education programs. Together with UCSB and LTER science education specialists, I develop the integrative themes that frame the work we do, particularly with K-12 students and teachers. These initiatives take two forms: research in science education and hands-on programming for students and teachers. Science Education Research: SBC LTER is currently a partner in two NSF-funded projects. CoastLines, funded through the ITEST program, is a teacher professional development project aimed at bringing GIS into middle and high school classrooms. Teachers work with LTER GIS data and develop curricula around LTER core research themes. Our summer PD program will occur at the SBC LTER site in 2010. Pathways to Ecological Literacy, funded through MSP, focuses on developing research-based environmental literacy learning progressions for 6-12 grades. Hands-on Programs: Our site-based programs bring teachers and students to the UCSB campus to increase content knowledge about key science concepts that relate to the SBC LTER research program. We focus on under-represented groups in the sciences by working with minority and female students as well as in schools with high percentages of minority and free/reduced lunch students.

Richard Zimmerman

Professor, Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA, USA 23529

Research Interests: Ecological physiology of marine autotrophs, radiative transfer and remote sensing of optically shallow waters, ecosystem productivity and numerical modeling

Role in SBC LTER: Associate Investigator

I am interested in light propagation and photosynthesis of submerged plant canopies. My work with the LTER involves the use of radiative transfer theory to model the absorption and scattering of light by the giant kelp. Accurate knowledge of absorption permits the calculation of important plant- and ecosystem-level properties such as rates of primary production, nutrient utilization and the amount of light available to understory algae. Knowledge of light scattering is being used to explore techniques for remote sensing quantification of the abundance and distribution of marine vegetation across a range of spatial scales.

Post Doctoral Associates

Jarrett Byrnes

Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.

Year and University of PhD: 2008 University of California, Davis

Research Interests: Marine Community Ecology

Role in SBC LTER: I am interested in characterizing the causes and consequences of ecological complexity in the kelp forests of Southern California. My experimental work concentrates on examining potential feedbacks between urchin grazing fronts and the diversity of sessile species on reefs subjected to disturbance from storms. I am also examining the consequences of wave disturbance to kelp forest food webs. During the past fifty years, average winter storm frequency and intensity has increased. These storms remove giant kelp, a foundation species that provides both habitat structure and food for rocky reefs. I am using long-term data records to look at the direct and indirect effects of wave disturbance on food web structure via changes in kelp abundance and productivity.

Melanie Fewings

Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.

Year and University of PhD: 2007, Woods Hole Oceanographic Institution/ Massachusetts Institute of Technology

Research Interests: Coastal Oceanography

Role in SBC LTER: I am examining the tidal and subtidal-frequency variations of water velocity, salinity, and temperature on the inner continental shelves of California's Channel Islands and along the mainland in the Santa Barbara Basin. Summertime cycles of large-scale coastal upwelling and upwelling relaxation are driven by winds and pressure gradients along the entire West Coast of North America from Washington to Baja Mexico. My research involves characterizing the inner-shelf manifestation of the upwelling/relaxation cycle in the Santa Barbara Basin, especially around the Channel Islands and near Point Conception. Little is known about the inner-shelf circulation around the Channel Islands, and the Islands are a particularly important region to understand due to the recent designation of marine reserves in the area.

Brian Kinlan

Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.

Year and University of PhD: 2007 University of California, Santa Barbara

Research Interests: Marine Ecology; Quantitative and Statistical Ecology; Remote Sensing

Role in SBC LTER: I am working with Investigators Reed and Siegel and SBC LTER graduate student Kyle Cavanaugh to acquire data and develop models to scale transect-scale observations of kelp forest dynamics to a regional ecosystem scale. Giant kelp forests are patchy and dynamic at multiple scales, only some of which are captured by conventional field survey methods. Our group's research is addressing this problem in three ways. First, we are developing new methods for extracting kelp forest area and biomass data from remote sensing (SPOT and Landsat images), using diver transect data for calibration and validation, leading to time series of southern California kelp biomass with unprecedented spatial and temporal resolution. Second, we are using spatio-temporal statistical modeling to quantify the relationship between kelp dynamics at local, short time scales and larger scale, longer-term patterns. Finally, we are developing a "seascape" model of the southern California giant kelp population that will integrate data on kelp abundance, biomass, productivity, and oceanographic forcing factors to reconstruct past kelp dynamics in unsampled areas, and forecast kelp dynamics under future scenarios.

Al Leydecker
Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, 93106.
Year and University of PhD: 2000 University of California, Santa Barbara
Research Interests: hydrology and aquatic chemistry
Role in SBC LTER: I am looking at nutrient export from catchments and tributaries in relation to rainfall patterns, topography, land cover, and land use. Annual variability in rainfall in these coastal watersheds leads to variations in annual runoff of up to three orders of-magnitude, and the variation in flux can be even greater. A major focus of my research is on determining how these factors interact to change the ecology of the Ventura River (one of the most biologically diverse streams within the SBC LTER region) by episodically creating conditions that trigger substantial algal blooms.

Robert J. Miller
Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, 93106.
Year and University of PhD: 2005, University of Massachusetts Boston
Research Interests: Marine ecology
Role in SBC LTER: I studied the partitioning of ecosystem production between giant kelp, understory macroalgae, and phytoplankton, and how non-kelp production is influenced by the canopy of giant kelp. Negative effects of giant kelp on non-kelp production means these two sources of carbon are complementary in space and time, potentially dampening spatial and temporal variation in ecosystem NPP. I also worked on the production of benthic understory foliose and turf algae, and the differential habitat roles of these assemblages. Currently I am working with Mark Page on application of new methods for characterization of particulate organic matter (POM) in the coastal ocean, and the roles of different components of POM in benthic food webs.

Andrew Rassweiler
Marine Science Institute, University of California, Santa Barbara, CA, USA, 93106.
Year and University of PhD: 2008 University of California, Santa Barbara
Research Interests: Marine Ecology
Role in SBC LTER: My main focus is on the mechanisms underlying sharp transitions in community state. Marine benthic systems are known for these sharp transitions, which manifest themselves both as spatial patchiness and as rapid changes in community composition. My graduate work used a combination of observational, experimental and theoretical approaches to explore the feedbacks that lead to these sudden shifts on reefs in the Santa Barbara Channel. I am continuing to pursue these

questions in my postdoc, working to synthesize our results from the SBC LTER with insights from other LTER sites. My interest in kelp forest community dynamics caused me to be very involved in developing the methods used by the SBC-LTER to estimate primary productivity by giant kelp, and I continue to be active in collaborative analyses of these data as well.

Graduate Students

Laura Carney
Degree Program: PhD, Joint Program in Ecology, University of California, Davis and San Diego State University
Status: graduating Dec 2009
Academic Advisor: Matt Edwards
Undergraduate Institution, Degree, Award Date: MA in restoration ecology from University of Washington 2003, BS Biology from Boston College 1997
Graduate Research Topic and relationship to SBC LTER: I am interested in the ability of kelps within southern California kelp forests to form gametophyte banks of mixed-age and mixed parental origin. These banks provide a source of rapid recovery from disturbance events like El Nino and have the potential to work in concert with current variability and variable dispersal to maintain elevated levels of genetic diversity within a population. I have performed both laboratory and field studies to identify the environmental factors that regulate delayed development. The SBC-LTER provided vital funding to utilize genetic techniques to examine genetic diversity within the Point Loma kelp forest and estimate delay durations of Macrocystis gametophytes and dispersal distances of Macrocystis zoospores.

Aubrey Cano
Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB
Status: 7th year
Academic Advisor: Craig Carlson
Undergraduate Institution, Degree, Award Date: San Francisco State University, BS, 2002
Graduate Research Topic and relationship to SBC LTER: I am examining dissolved organic matter (DOM) release mechanisms as a function of changing trophic complexity and varying phytoplankton species. In addition to the impact DOM source quality has in determining its fate. These questions are being examined via experimental manipulation and I hope to be able to tie my results into a better understanding of marine organic carbon flow especially with regard to the microbial food webs and organic carbon accumulation as well as export from surface to deeper waters leading to oceanic carbon sequestration. I am currently a teaching fellow with the new NSF LTER cross-site Math and Science Partnership Program. In this capacity I am using SBC LTER developed education tools and working closely with SBC LTER researchers and education coordinators to enhance science activities and education in K-12 classrooms..

Kyle Cavanaugh
Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB.
Status: Fourth Year
Academic Advisor: David Siegel
Undergraduate Institution, Degree, Award Date: Trinity University, BA, 2003
Graduate Research Topic and relationship to SBC LTER: I am studying the spatiotemporal variability of giant kelp biomass and production across multiple scales of observation. My research combines satellite and aerial remote sensing with detailed

field measurements to scale up local observations to larger areas and longer times. The spatiotemporal variability we measure with our multi-scaled observations will then be linked to press and pulse environmental drivers which also operate across a spectrum of scales (wave action, SST, nutrients, predation, bottom sedimentation, etc.). My project relies heavily on detailed field sampling of giant kelp biomass, frond density, and NPP conducted by the SBC LTER. In addition, the information management resources provided by the SBC LTER will allow me to archive the data products extracted from my extensive time series of satellite and aerial data.

Helene Finger

Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB.
Status: Third Year
Academic Advisor: Eckart Meiburg, & Sally MacIntyre
Undergraduate Institution, Degree, Award Date: California Polytechnic State University, San Luis Obispo, BS, 1988
Graduate Research Topic and relationship to SBC LTER:I am interested in applying fluid mechanics principals to coastal ocean flow processes, specifically studying transport and mixing of hypopycnal (positively buoyant) freshwater plumes in the near coastal region. Relatively few studies have been carried out within 500 m of the coast since this region is too close to shore to be studied from ships or remote sensing techniques. The SBC LTER is providing initial data for me to utilize in my preliminary research on the advection and dispersion of freshwater plumes in the Santa Barbara nearshore region. SBC LTER will also provide assistance with identifying, obtaining and analyzing the additional data required to define the advection and dispersion of freshwater plumes from small coastal watersheds in the Santa Barbara Channel.

Jo Goodman

Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB.
Status: Third Year
Academic Advisor: Brzezinski
Undergraduate Institution, Degree, Award Date: Texas A&M at Galveston, B.S., 2005
Graduate Research Topic and relationship to SBC LTER: Understanding of the processes that control variability in nutrient transport off of Southern California is complicated by the very narrow continental shelf (2-5 km) in this region, which creates a more direct connection between shallow reefs and deeper oceanic waters. The Santa Barbara Channel (SBC) is one of these environments. The motivation for the SBC LTER Cross Shelf Study is to gain an understanding of how environmental gradients across the continental shelf of the SBC give rise to different phytoplankton community types and resource responses, and to observe how seasonal changes in nutrient regimes create changes in the phytoplankton community. As a graduate student I lack the experience, funds or field assistance to collect data on ecosystem level processes. The SBC LTER is providing me with a framework in which to formulate my project and the financial assistance, as well as the personnel, to collect the necessary data. Now I have meaningful data (in analysis) on the cross shelf gradients that exist within the phytoplankton community of the SBC, and the processes that drive these gradients. The SBC LTER was an integral part of the field research I have completed and the data analysis that is ongoing as I work toward my dissertation. I am also aware of the wealth of data that has already been collected under the SBC LTER, and I plan to utilize this data to support my dissertation project.

Blair Goodridge

Degree Program: PhD, Donald Bren School of Environmental Science and Management, UCSB.
Status: 2nd Year

Academic Advisor: John Melack
Undergraduate Institution, Degree, Award Date: Colgate University, BA, 2003
Graduate Research Topic and relationship to SBC LTER: I plan to look at the biogeochemical dynamics of beach groundwater; specifically, how beaches might function as import areas of organic matter mineralization and nutrient transformation and/or removal. These processes may be important for the maintenance of coastal primary production and ecological stability. The SBC LTER will provide long-term data on kelp primary production and watershed nutrient loading to the ocean, which will allow a more complete relative understanding of the importance of beaches to the maintenance of coastal ecological integrity.

Carla Guenther
Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB
Status: Finishing (7th year)
Academic Advisor: Lenihan, Carr
Undergraduate Institution, Degree, Award Date: Worcester Polytechnic Institute, BS, 1997
Graduate Research Topic and relationship to SBC LTER: Ecological research often tests anthropogenic drivers as mechanisms of environmental change. Ecological Anthropology examines human adaptation to their environment. The reflexive relationship between human systems and their ecological counterpart was not often explored until the development of socio-ecological approaches that focus on the interaction of human and natural systems. Using this perspective I study the Santa Barbara regional commercial lobster trap fishery's relationship with the kelp forest communities on which lobster depends. I combine a synthesis of SBC LTER ecological data with fishery-dependent log book and socio-economic interview data to determine: (1) the effects of fishing on lobster populations and, indirectly, kelp forests; (2) the effects of environmental change (i.e. kelp loss) on lobster fishing effort and catch. I am also investigating how lobster fishing's relationship with its ecological context affects desired management outcomes. Marine Protected Areas (MPAs) are a management tool employed at the Channel Islands that has removed lobster fishing from 17% of the nearshore fishing grounds. Using ten seasons of logbook and fishery interview data I am testing the impacts of the 5 year old Channel Islands marine reserves on the catch, revenue, and social structure of the regional lobster fishery. The SBC LTER supplied funding and kelp reef monitoring data essential to the execution of this research and paid my stipend and tuition for two academic quarters.

Elisa Halewood
Degree Program: MA Interdepartmental Graduate Program in Marine Science, UCSB
Status: 3rd year
Academic Advisor: Craig Carlson
Undergraduate Institution, Degree, Award Date: University of California, Santa Barbara, B.S., Cell & Developmental Biology 2004, University of California, Santa Barbara, B.A., Italian Studies 2004.
Graduate Research Topic and relationship to SBC LTER: My primary area of research is Microbial Oceanography. I am interested in the biogeochemical cycling of dissolved organic carbon (DOC) in the marine environment through heterotrophic bacterioplankton processes. DOC serves as an organic substrate for heterotrophic microbial production, and as a result of this production organic matter is then re-mineralized. DOC availability and microbial processes therefore have important implications for the distribution of nutrients in marine ecosystems. A preliminary study conducted by SBC LTER in 2005 showed that while DOC concentrations were observed to be low in offshore waters of the SB channel (equal to or less than oligotrophic values), in the near shore there was at times a large accumulation of DOC

resulting in a striking gradient extending from Mohawk Kelp Forest several km into the Channel. In the Santa Barbara Coastal ecosystem, a unique case exists in that the continental shelf is extremely narrow (being only a few km wide in areas), allowing greater potential for exchange between near shore rocky reef ecosystems and offshore waters. In response to these observations, my Masters' research project was designed to assess the temporal and spatial variability of organic nutrients and heterotrophic bacteriplankton dynamics across this near shore shelf system. 16 monthly oceanographic cruises were conducted from January 2008-April 2009 along a transect from Mohawk Kelp Forest 3km into the channel. Measurements of dissolved and particulate organic matter, inorganic nutrients, and bacterioplankton abundance, activity and community structure were carried out. Results will give a better understanding of biogeochemical cycling of organic matter in this near shore ecosystem.

Shannon Harrer

Degree Program: MA, Department of Ecology, Evolution and Marine Biology, UCSB

Status: First Year

Academic Advisor: Holbrook, Reed

Undergraduate Institution, Degree, Award Date: BS Biology, UCSB, 2005

Graduate Research Topic and relationship to SBC LTER: Rocky reef ecosystems are largely dominated by giant kelp, Macrocystis pyrifera, whose quick growth and monopolization of light is well documented as a mechanism for competitive exclusion among most benthos associated primary producers. Relief from intense competition for light is accomplished through disturbance events associated with large winter swells that forcefully uproot Macrocystis individuals reduce surface canopy density and allow ample light to reach the seafloor. To better understand patterns, causes, and ecological consequences of change in understory algal productivity, I am working to develop a logistically simple model incorporating irradiance, photosynthesis vs. irradiance and understory algal abundance data collected by the SBC LTER.

Matt Kay

Degree Program: PhD. Donald Bren School of Environmental Science and Management, UCSB.

Status: Fourth Year

Academic Advisor: Hunter Lenihan

Undergraduate Institution, Degree, Award Date: University of Oregon, Biology, 1996

Graduate Research Topic and relationship to SBC LTER: I study the related impacts of fishing and marine protected areas (MPAs) on populations of California spiny lobster (Panulirus interruptus). At the Santa Barbara Channel Islands, where I conduct my fieldwork, these impacts appear to be moderated by specific habitat features that are spatially heterogeneous. Responsible assessment of population responses to fishing and MPA protection must consider the influence of habitat. I monitor lobster populations by working with commercial fishermen to trap and tag lobsters inside and outside of MPAs (~18,000 animals tagged to date). Additionally, the SBC LTER has provided me with training and oversight (SBC LTER PI Dan Reed is on my thesis committee) to conduct subtidal SCUBA surveys at areas where I conduct trapping surveys. This dual trap/SCUBA assessment strategy shows great promise for relating fishery and/or MPA performance to the physical and community structure of individual reefs. This approach also permits detailed study of ecological predictions for MPAs (e.g., species shifts, trophic cascades, etc.). The implementation of an MPA network along the southern California coast, as mandated by MLPA, is well underway and apparently imminent. I look forward to working with the SBC LTER and coastal fishermen to apply our trap/SCUBA approach to monitor the ecological and fishery impacts of these new coastal MPAs.

Kerry J. Nickols
Degree Program: PhD, Ecology, University of California, Davis
Status: Ph.D. Candidate, 5th year
Academic Advisor: Gaylord, Largier (UC Davis)
Undergraduate Institution, Degree, Award Date: University of California, Berkeley, BA, 2002
Graduate Research Topic and relationship to SBC LTER: I study the movement of ocean waters near the coast and its implications for inner shelf exchange, larval recruitment, and other ecological processes relevant to kelp forest ecosystems. My dissertation research has focused on the interaction of the coastline and alongshore water flow, which creates a nearshore velocity gradient (termed the coastal boundary layer, CBL) whose properties are poorly defined. Thus far, I have focused on quantifying the CBL at sites along the California coast, including the SBC LTER. My research has benefited from the core hydrodynamic moorings of the SBC LTER, which I augmented with additional instrumentation to create cross-shore transects of current meters. These transects extend to within tens of meters of the shore, into regions where empirical data are historically sparse. I have documented robust patterns at all sites of an increase in alongshore velocity with an increase in distance from the coast and depth. Results suggest an improved ability to quantify nearshore flows, facilitating a better understanding of processes underlying local retention of certain waterborne constituents, such as larvae and pollutants. Further modeling studies using this nearshore velocity data from the SBC LTER will elucidate connections between nearshore kelp forests and offshore ecosystems.

Daniel K. Okamoto
Degree Program: PhD, Department of Ecology, Evolution and Marine Biology, UCSB
Status: First Year
Academic Advisor: Reed, Holbrook
Undergraduate Institution, Degree, Award Date: University of Washington, BS (Biology, minor in Aquatic and Fishery Sciences), 2005, University of Alaska Fairbanks, MS (Fisheries), 2009
Graduate Research Topic and relationship to SBC LTER As a first year PhD student, I am broadly interested in how local mechanisms give rise to species dominance, local extinction, and coexistence. Kelp forests, because of their rapid dynamics, immense productivity, and geographic location provide a unique opportunity to address fundamental and important unanswered ecological questions with regards to how kelps become dominant, fluctuate through time, and influence other algae, fish and invertebrate communities. The SBC LTER program drew me to Santa Barbara as it provides a wholly unique opportunity to study the dynamics of giant kelp populations. While my masters research in Alaska allowed me to investigate kelp forest dynamics in a nearly unexplored setting; a principle drawback of such settings is that no long-term data exist to relate small scale experiments to long term fluctuations. Questions I may address during my PhD include 1) how giant kelp (*Macrocystis pyrifera*) colonizes and re-establishes dominance (or fails to do so) after various types of large-scale disturbances (such as storm events or persistent urchin barrens); 2) how giant kelp dominance influences the dynamics and productivity of macroalgal assemblages; and 3) how variable macroalgal assemblages differentially generate spatial subsidies to external environments by exporting organic matter or altering the productivity of transient mobile fauna. Such goals can be achieved using a combination of experiments in situ in the SBC LTER, laboratory methodologies, as well as by utilizing the data generated by the program thus far.

Sarah Rathbone
Degree Program: PhD, Interdepartmental Graduate Program in Marine Science, UCSB
Status: First Year
Academic Advisor: Hunter Lenihan, Steve Gaines
Undergraduate Institution, Degree, Award Date: Bryn Mawr College, BA, 2006
Graduate Research Topic and relationship to SBC LTER: I'm interested in evaluating different fisheries management strategies in the Santa Barbara Channel and determining the underlying ecological mechanisms that lead to successful implementation and sustainable extraction. Specifically, I will examine the spatial heterogeneity of populations and habitat structure as important considerations when employing different management policies. The SBC LTER kelp forest monitoring program provides critical and comprehensive base-line data on population dynamics and trophic interactions that I will utilize in my research on informing future fisheries management decisions. The advent of ecosystem-based fisheries management has highlighted the importance of long-term datasets like those conducted by SBC LTER researchers. I am also a teaching fellow with the new NSF LTER cross-site Math and Science Partnership Program in which I work closely with SBC LTER researchers and education coordinators to enhance science activities and education in middle school classrooms.

Gabriel Rodriguez
Degree Program: PhD, Department of Ecology Evolution and Marine Biology, UCSB.
Status: Second Year
Academic Advisor: Reed, Holbrook
Undergraduate Institution, Degree, Award Date: California State University, Monterey Bay, BS, 2008
Graduate Research Topic and relationship to SBC LTER: My research topic includes investigating how the interaction of abiotic factors such as temperature, nutrient supply, and wave force affect the rate of frond loss in a kelp forest. Better predicting frond loss in the face of global climate change has implications in predicting giant kelp metapopulation dynamics and biomass production. The SBC LTER is providing me with a complete suite of valuable long-term data at different sites along the Santa Barbara Coastline, including: *Macrocystis* tissue chemistry, water temperature, wave and current data, community composition data, and frond loss data. This data is essential to my research, and extends the inference space to a much larger scale than would otherwise be possible for a graduate student research project.

Tanique Rush
Degree and Program: MS, Oceanography, Old Dominion University
Status: Second Year
Academic Advisor: Richard Zimmerman
Undergraduate Institution, Degree, Award Date: University of North Carolina Wilmington, B. S. in Marine Biology with a minor in Chemistry, May 2005
Graduate Research Topic and relationship to SBC LTER: My primary research goal is to gain a better understanding of remotely sensed kelp data. I am currently evaluating hyperspectral imagery to assess our ability to retrieve reliable biomass and productivity data. The effect of image resolution on the retrieval of this information is of great importance. I am also interested in determining the effect of resolution on kelp patches, and the resulting ecological implications. My research has greatly benefitted from the data collected at the SBC LTER site, which is the basis of my entire study.

Nicholas Schooler
Degree Program: MA, Interdepartmental Graduate Program in Marine Science, UCSB
Status: First Year
Academic Advisor: Dugan, Gaines
Undergraduate Institution, Degree, Award Date: University of California, Santa Barbara, BA, 2006
Graduate Research Topic and relationship to SBC LTER :I am interested in the status and trends in biodiversity and ecological function of sandy beach ecosystems, which make up ~75% of the California coastline. My research will evaluate hypotheses concerning alteration in intertidal biodiversity as a result of shifts in species distributions along with habitat change in response to climate change, other press and pulse environmental drivers, and a variety of anthropogenic activities over the last 30+ years using a combination of historic, mid-range and new datasets. My project will benefit from the core research on SBC beaches and historic and modern data on the abundance of giant kelp, a key resource for beach ecosystems, collected by the SBC LTER for my analyses. SBC-LTER will also be a source of expertise and digital infrastructure needed to archive the newly aquired historic datasets from California beaches.

Catherine Shields
Degree Program: PhD, Donald Bren School of Environmental Science and Management
Status: Third Year
Academic Advisor: Christina Tague
Undergraduate Institution, Degree, Award Date: UNC-Chapel Hill: B.S. Environmental Science (2004), M.A. Geography (2007)
Graduate Research Topic and relationship to SBC LTER: My research focuses on the impacts of urbanization on vegetation water use and function in semi-arid environments. The primary goal of my dissertation research is to quantify the role of impervious surface area and fine scale basin connectivity on vegetation water use, and develop methods for capturing these processes at a coarser scale in an ecohydrologic modeling framework. My project will benefit primarily from the stream discharge and chemistry data collected by the SBC-LTER. I have been using this data to calibrate and evaluate the ecohydrologic model I am using for my dissertation analyses, and anticipate future use of this and potentially other data collected by SBC LTER.

James Watson
Degree Program: PhD, Interdepartmental Graduate Program in Marine Science
Status: 4th year
Academic Advisor: David Siegel
Undergraduate Institution, Degree, Award Date: Bristol University (UK), B.Sc, 2001
Graduate Research Topic and relationship to SBC LTER: I have a strong desire to find out how things in nature work. However, this is a problem because the natural world is difficult to understand. It is filled with processes that are a) spatial, b) dynamic, c) non-linear and d) very difficult to observe. I am interested in building interdisciplinary approaches to tackling these sorts of problems. Currently I am working on understanding how ocean circulation affects the dispersal of marine species' larvae and what consequences there might be for population demography and our approaches to management. I use theoretical tools such as discrete population models and network theory and I have also dabbled in comparing my work with empirical studies. Understanding how marine populations are connected by ocean circulation is key to spatial marine management methods such as the design of marine protected area networks.

Jono Wilson

Degree Program: PhD, Donald Bren School of Environmental Science and Management, UCSB.

Status: 4th year

Academic Advisor: Hunter Lenihan

Undergraduate Institution, Degree, Award Date: UCSB, Business/Economics and Environmental Studies, June 2000

Graduate Research Topic and relationship to SBC LTER: In collaboration with commercial fishermen, UCSB scientists, and state resource managers I am conducting a collaborative mark and recapture study inside and out of five northern Channel Islands Marine Protected Areas (MPAs). On board commercial fishing vessels I am using commercial fishing gear to tag and release commercially important fishes at 3 reefs inside each reserve and 3 reefs outside each reserve at set distances from the reserve border. The goals of this study are to 1) explore the mechanisms driving variability in size structure and catch-per-unit-effort of commercially harvested nearshore finfish inside and outside of the northern Channel Islands MPAs across an environmental gradient, 2) Develop a theoretical model for managing nearshore fishes using comparisons of fished and unfished areas, 3) Examine the fishery benefits of managing at spatially explicit scales using MPAs as reference sites compared to the status quo of managing at regional scales. The SBC LTER is providing a wealth of time series data for me to use for determining the mechanisms that drive catch rates of nearshore finfish. I will also use these time series data to incorporate into a model that sets harvest rates. By understanding the ecological forces acting on the distribution and abundance of certain nearshore fishes, I will be able to more accurately adjust recommended catch rates in relation to environmental conditions.