COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 11-1 **NSF 12-524** **03/21/12**	FOR NSF USE ONLY NSF PROPOSAL NUMBER **1232779**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **DEB - Long-Term Ecological Research**	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☒ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
956006145	0620276	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **University of California-Santa Barbara**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Office of Research** **Rm 3227 Cheadle Hall** **SANTA BARBARA, CA 93106-2050**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0013201000**	
NAME OF PRIMARY PLACE OF PERF **University of California-Santa Barbara**	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE **University of California-Santa Barbara** **Marine Science Institute, MC6150** **Santa Barbara ,CA ,931066150 ,US.**

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **LTER: Land/Ocean Interactions and the Dynamics of Kelp Forest Ecosystems (SBC III)**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,880,000	72 months	12/01/12	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
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- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT **Marine Science Institute**	PI/PD POSTAL ADDRESS **Santa Barbara, CA 93106** **United States**
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PROJECT SUMMARY

Intellectual Merit:

The Santa Barbara Coastal LTER (SBC) is an interdisciplinary research and education program established in April, 2000 to investigate the role of land and ocean processes in structuring ecosystems at the land-sea margin. Our study main area is the Santa Barbara Channel and the steep coastal watersheds, small estuaries and sandy beaches that drain into it. The focal ecosystem of our research is giant kelp forests, a diverse and highly productive marine ecosystem that occurs on shallow rocky reefs at the interface of the land-sea margin in the Santa Barbara Channel and other temperate regions throughout the world. The major emphasis of our proposed work is developing a predictive understanding of the structural and functional responses of giant kelp forest ecosystems to environmental forcing from the land and the sea. The amount of nutrients and organic matter delivered to the kelp forest from land and the surrounding ocean varies in response to changes in climate, ocean conditions and land use. Variation in the supply of these commodities interacts with physical disturbance to influence the abundance and species composition of kelp forest inhabitants and the ecological services that they provide. The overarching question motivating our proposed research is:

How are the structure and function of kelp forests and their material exchange with adjacent land and ocean ecosystems altered by disturbance and climate?

To address this question our research will focus on three themes: (1) biotic and abiotic drivers of kelp forest structure and function, (2) material exchange at the land-ocean margin, and (3) movement and fluxes of inorganic and organic matter in the coastal ocean. The relevance of our research is far reaching as we address fundamental questions pertaining to biodiversity and ecosystem function, vulnerability and resilience of communities to climate change and fishing, the roles of land use and fire on landscape change and watershed hydrology, and the physics of dispersal in the little studied coastal waters of the inner continental shelf. The dynamic nature of kelp forests, including their frequent disturbance and rapid regeneration coupled with high productivity and diverse food webs make them ideal systems for investigating ecological questions that require decades to centuries to address in other ecosystems. Our research will utilize a variety of approaches including: (1) coordinated long-term measurements, (2) manipulative field experiments, (3) measurement-intensive process studies, and (4) integrated synthetic analyses and modeling that allow for predictions beyond the spatial and temporal scope of our measurements, and help guide future research. SBC's information management system, which focuses on data organization, integrity, preservation and web-based public access geared for a variety of end users will facilitate these efforts.

Broader Impacts:

Education and training are tightly integrated into all aspects of our research. We have successfully developed a multifaceted, interdisciplinary approach to education and outreach that highlights research interests of SBC investigators, students, and the general public. Our programs include active links with K-12 students and teachers that target historically under-represented groups from underserving, low-achieving schools. We are also very proactive in undergraduate and graduate student training, direct public outreach, and productive interactions with the media, government agencies and local industries. We will continue these outreach and education programs and maintain our efforts to attract additional funding to support them. We are committed to sharing our research results with resource managers, decision makers, stakeholders, and the general public who are interested in applying our findings to policy issues concerning natural resources, coastal management, and land use.

SECTION 1 - RESULTS FROM PRIOR SUPPORT

SBC LTER II: Land/Ocean Interactions and the Dynamics of Kelp Forest Communities. Grant No. OCE-0620276, Funding (2006-2012) = $4,860,000 (plus supplements)

The Santa Barbara Coastal LTER (SBC) is an interdisciplinary research and education program established in April 2000 to investigate the relative importance of land and ocean processes in structuring coastal ecosystems. Its principal study domain is a 10,000 km^2 area that includes the Santa Barbara Channel (located in the northern portion of the Southern California Bight) and the steep coastal watersheds, small estuaries and sandy beaches that drain into it (Figure 1). The focal ecosystem of SBC is giant kelp (*Macrocystis pyrifera*) forests, a diverse and highly productive marine ecosystem that occurs on shallow rocky reefs at the interface of the land-sea margin in the Santa Barbara Channel and other temperate regions throughout the world. Not only are giant kelp forests ecologically important to the areas in which they occur, but they also provide highly valued provisioning, cultural and regulating services (e.g., fisheries, mariculture, pharmaceuticals, recreation, tourism, aesthetics, and biodiversity conservation; Foster and Schiel 1985, Leet et al. 1992).

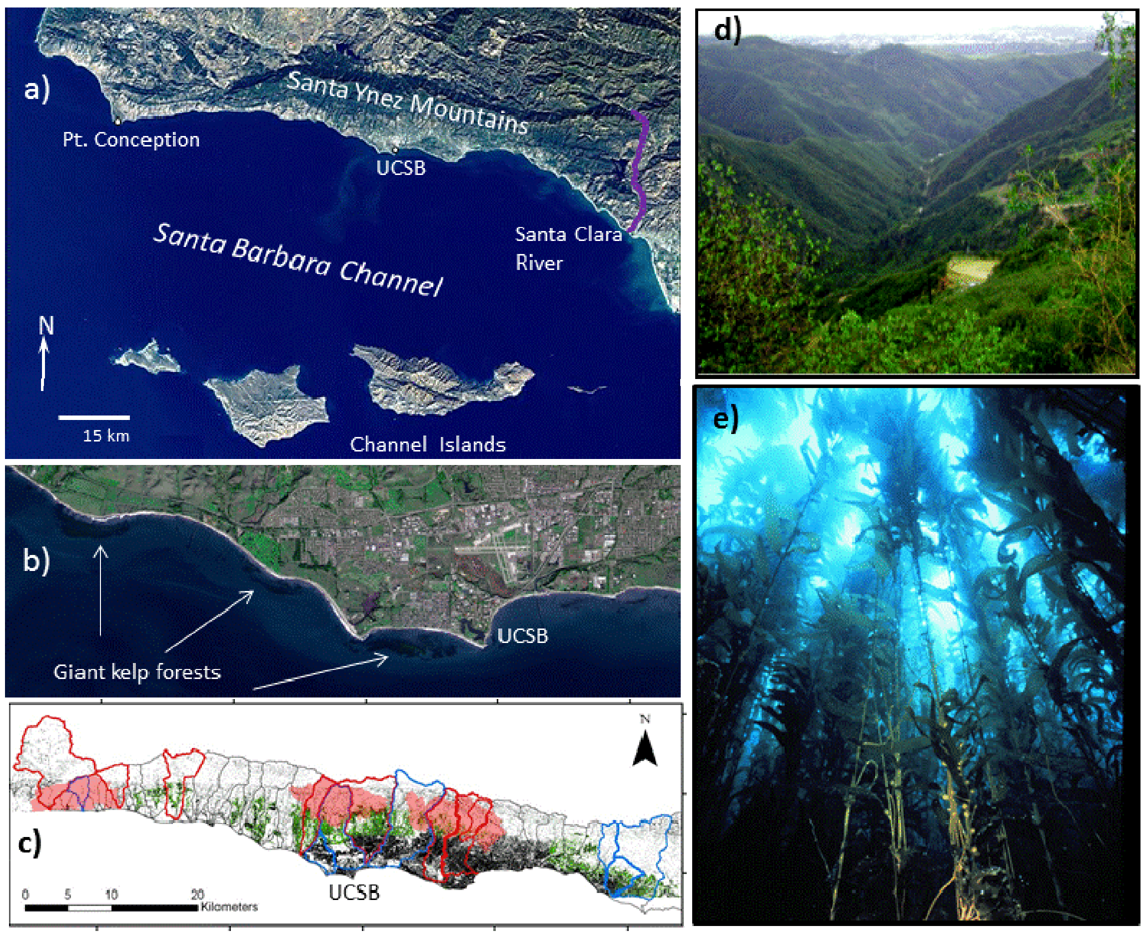

Figure 1. (a) Map of the SBC study domain, (b) Satellite image showing the close proximity of giant kelp forests to the land-sea interface, (c) Land cover of SBC watersheds: green = agriculture, black = urban/suburban, white = undeveloped, pink = recently burned in 2004, 2008 and 2009. Catchments with red borders are currently sampled; catchments with blue borders were previously sampled. (d) Typical SBC watershed with steep slopes and narrow canyons, (e) Submarine view of a giant kelp forest.

Habitat	Variables measured	Spatial extent	Sampling frequency	Year initiated
Land	• Stream chemistry (nitrate, ammonium, phosphate, total dissolved nitrogen, particulate nitrogen, total dissolved phosphorus, particulate phosphorus, particulate organic carbon), total suspended sediments, conductivity • Stream discharge • Precipitation (tipping bucket SBC/SB County)	• 9 sites • 9 sites • 10/16 sites	• Event-based and weekly to biweekly • Continuous • Continuous	• 2000-2005 • 2002-2005 • 2002
Beach	• Biomass & species composition of macroalgal wrack • Abundance of birds • Abundance of invertebrate wrack consumers	• 5 sites • 5 sites • 5 sites	• Monthly • Monthly • Annually	• 2008 • 2008 • 2011
Kelp forest	• Population abundances of > 200 species of kelp forest algae, invertebrates, and fish • Water temperature on the bottom • Irradiance at the surface and bottom • Foraging habitat, prey biomass, surfperch density and size structure • Giant kelp canopy area and biomass from Landsat • Giant kelp biomass, growth, loss, NPP and stoichiometry • H & N isotope composition of sediments & consumers	• 11 sites • 11 sites • 5 sites • 11 sites • S. Cal. Bight • 3 sites • 5 sites	• Annual • 15 min • 1 min • Annual • 1-2 months • Monthly • Seasonally	• 2000 • 2002 • 2008 • 1982 • 1984 • 2002 • 2012
Inshore Ocean	• Current velocity, conductivity, & temperature from moored instruments • Dissolved and particulate nutrients (C, N, P, Si), chlorophyll a • Invertebrate larval settlement • pH	• 5 sites • 5 sites • 6 sites • 4 sites	• 5 min • Monthly • 2 weeks • 10 min	• 2002 • 2002 • 1990 • 2012
Offshore Ocean	• Sea surface temperature, chlorophyll a, sediments from satellite remote sensing	• S. Cal. Bight	• 1-2 days	• 1997

Table 1. Core long-term measurements planned for SBC III.

RESEARCH RESULTS

The primary focus during our first 6-year funding cycle (SBC I) was identifying and quantifying inputs to giant kelp forest communities from land and the ocean and documenting patterns and sources of spatial and temporal variation in key elements of kelp forest structure and function. We established a core group of long-term integrated measurements aimed at quantifying inorganic and organic subsidies to giant kelp forests in the Santa Barbara Channel and their effects on kelp forest community structure, productivity and dynamics (Table 1, Supplement 1a).

During SBC II we sought to determine how environmental drivers acting over different spatial and temporal scales interact to influence the community structure and ecological functions of giant kelp forests. Our research approach to this overarching topic focused on three general themes: (1) the influence of environmental drivers on exchange rates of nitrogen and carbon between giant kelp forests and adjacent land and ocean habitats, (2) the direct effects of key environmental drivers on kelp forest community structure and function, and (3) the indirect effects of environmental drivers on kelp forest community structure and function and the feedbacks between structure and function. The ten publications that resulted from SBC II that are most significant for motivating the research proposed here (SBC III) are referenced in **bold** in this section, Section 2 Proposed Research and in References Cited. A complete list of SBC publications can be found at http://sbc.lternet.edu/cgi-bin/publications.cgi. A list of all SBC's electronically available data sets and documentation of their usage is in Supplement 1.

Below we summarize the major research findings from SBC II that motivate the research proposed for SBC III. More complete information on our research activities and findings is in our 2011 annual report http://sbc.lternet.edu/external/Documents/Progress_Reports/2006award/Annual_Reports/.

1. The influence of environmental drivers on exchange rates of nitrogen and carbon between giant kelp forests and adjacent land and ocean habitats

Like many coastal ecosystems, kelp forests are influenced by processes occurring on land and in the open ocean. Streams and rivers transport nutrients and organic matter from land to coastal waters, while ocean currents supply nutrients and organic matter from adjacent offshore waters. Short and long-term changes in climate that alter rainfall, fire, ocean currents, the depth of the thermocline and other environmental factors affect the temporal and spatial delivery of these materials to kelp forests. Since the beginning of the SBC LTER we have conducted hydrological and hydrochemical measurements in the watersheds that drain into the Santa Barbara Channel and oceanographic measurements within the Channel to better understand the factors that determine the delivery of nitrogen and carbon to kelp forests in the region.

Our ongoing time series measurements in a diverse array of watersheds and sub-catchments reveal that stream discharge and fluxes of dissolved and particulate nutrients and suspended sediments vary greatly as a function of land cover and land use, rainfall amounts and disturbance from fire. For example, annual nitrate fluxes ranged from 0.5 moles/ha to 1100 moles/ha among the watersheds we have studied, while inter-annual variation in nitrate flux varied by almost two orders of magnitude among watersheds (Figure 2). Concentration versus runoff relationships showed consistent nitrate-runoff patterns within three broad land use classes (dilution in agricultural watersheds, invariance in urban watersheds, and enrichment in an undeveloped

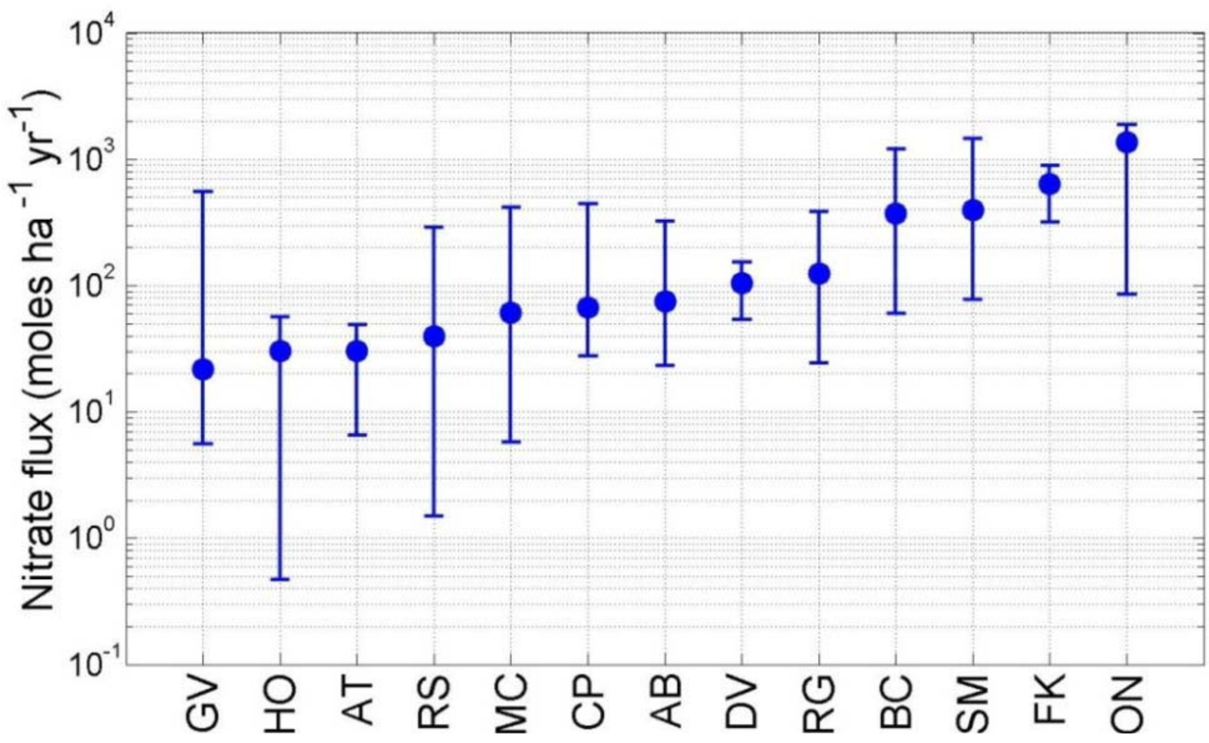

Figure 2. Median annual flux of nitrate from 13 SBC coastal catchments. Vertical bars denote ranges. Abbreviations for catchments are as follows: Gaviota (GV), Arroyo Hondo (HO), Atascadero (AT), Rattlesnake (RS), Mission (MC), Carpinteria (CP), Arroyo Burro (AB), Devereux (DV), Refugio (RG), Bell Canyon (BC), Santa Monica (SM), Franklin (FK) and San Onofre (ON). During the period represented the San Onofre watershed burned completely and the lower portions of Gaviota and Arroyo Hondo burned.

watershed) that were reproduced by a hydrochemical mixing model (**Goodridge and Melack in review**). Surprisingly, we found that stream nitrate concentrations during periods of stormflow were less variable than during baseflow regardless of land use and source of nitrate.

We found that dissolved organic nitrogen (DON) and particulate nitrogen (PN) contributed significantly to the nitrogen exported from streams. DON fluxes were often comparable to nitrate fluxes, while PN fluxes were often twice as high as total dissolved nitrogen fluxes. The latter may be a particularly important source of nitrogen to nearshore food webs. We observed a pattern of ^{15}N-enrichment in two common benthic kelp forest consumers (the sea urchin *Strongylocentrotus purpuratus* and the annelid *Diopatra ornata*) with increasing influence of runoff suggesting that terrestrially-derived nitrogen enters the kelp forest food web indirectly through a trophic intermediary such as microbes or benthic algae (Page et al. 2008). Recent hydrogen isotopic analyses show that terrestrially-derived particulate organic matter is broadly distributed in nearshore sediments, especially following rainfall events (Figure 3). The remineralization of this material could provide an important source of nitrogen to nearshore producers, particularly during times of the year when oceanic sources of nitrogen are low, and we propose to investigate this phenomenon in SBC III (Proposed Research THEME 3b).

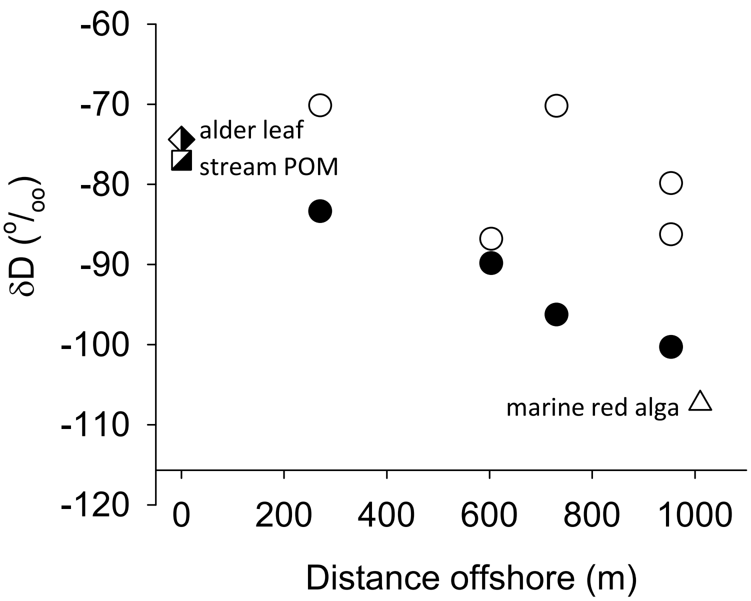

Figure 3. Variation in δD values of fine sedimentary particulate organic matter (POM) with distance offshore in Goleta Bay in March 2010 (○) and August 2010 (●). More positive δD values suggest larger terrestrial contributions to sediment POM as indicated by reference δD values for alder leaf, stream POM and the common marine alga *Acrosorium ciliolatum*. Sediment POM samples collected in March followed a rainfall event.

Fires in coastal watersheds of southern California result in episodic alternations in hydrology and export of nutrients and suspended sediment to coastal waters with a recurrence interval of 10 to 50 years. Stream and rainfall gauging and runoff sampling were used to determine changes in hydrology and export of nutrients and suspended sediment from several wildfires in 2004, 2008 and 2009 that burned coastal watersheds in our study area (Coombs 2006, Coombs and Melack in review). Burned watersheds had an order of magnitude higher peak discharge compared to unburned watersheds and exported an order of magnitude more sediment. Highly elevated ammonium export from burned watersheds occurred during the first storms of the rainy season and was 30 times greater than from unburned watersheds. Nitrate, DON, and phosphate export from burned watersheds increased several fold as well. Determining the trajectory of recovery of burned watersheds requires continued measurements of discharge and material fluxes complemented by remote sensing and field studies of vegetation regrowth and associated changes in soils, which we will pursue in THEME 2A and 2B of our proposed research.

We used our rainfall-runoff modeling (Beighley et al. 2003) in conjunction with empirical relationships among discharge, land cover and nutrient fluxes to extend our estimates of fluxes (both backward and forward in time) to the mainland watersheds bordering the Santa Barbara Channel. Specifically, we combined the frequency distribution of runoff events with relationships between nutrient export and runoff to show that in ENSO years, rainfall events may increase concentrations of nitrate and phosphate 5 to 10 times above ambient levels in nearshore waters (**Beighley et al. 2008**). Additionally, we developed nitrate and phosphate export coefficient models based on measurements of nutrient fluxes in streams from specific land use classes and included a watershed response function that scaled export up or down depending on antecedent moisture conditions (Robinson 2006, Robinson and Melack in review). More sophisticated modeling that incorporates biogeochemical processes into estimates of regional watershed-scale fluxes is proposed for SBC III to more accurately predict the export of nutrients into the coastal ocean for the wide range of watershed types, fire regimes and climate conditions characteristic of southern California (Proposed Research THEME 2A). The dispersal of these exported materials in the coastal ocean will be studied in Proposed Research THEME 3A.

These measurements of outputs from the watersheds are complemented by studies of nutrient dynamics in the coastal ocean. The main elements of our oceanographic sampling include monthly small boat surveys to characterize chemical and biological properties of seawater, an array of shallow water instrumented moorings to measure physical properties of seawater (e.g., subsurface currents, temperature, irradiance and conductivity), high frequency (HF) radars for measuring surface currents, a series of channel-wide oceanographic cruises onboard UNOLS vessels, and remote sensing from satellite imagery. Data from these sources revealed high levels of phytoplankton biomass in the central portion of the western Santa Barbara Channel and the inshore portion of the eastern Channel along the mainland coast (Shipe and Brzezinski 2001, **Brzezinski and Washburn 2011**). Our analyses of the prevailing circulation place these regions of high biomass upstream from extensive kelp forests along the mainland coast (Otero and Siegel 2004). Data from a series of UNOLS ship cruises revealed that high phytoplankton biomass and productivity along the mainland coast in the Channel is supported by the vertical supply of nutrients from wind-driven coastal upwelling. A productivity maximum exists in the western Channel supported by cyclonic circulation that indicates upwelling through isopycnal uplift coupled with particle retention (**Brzezinski and Washburn 2011**). On the mainland continental shelf, surveys from small boats revealed that as upwelling relaxed and inorganic nutrients were drawn down, suspended dissolved and particulate organic matter (DOM and POM) increased reaching maxima by late spring/early summer (Halewood et al. in review). During this period marked spatial gradients in DOM and POM were observed with maxima developing closest to kelp forests. These findings show that the high phytoplankton production along the mainland coast in the eastern channel is associated with strong, but intermittent cross-shelf gradients in biological and biogeochemical properties, which indicate rapid cross-shore delivery of nutrients and phytoplankton produced on the outer shelf during spring, but significant isolation of the inner shelf from offshore processes under stratified conditions during late summer and fall (Goodman et al. in review, Halewood et al. in review).

The supply of phytoplankton to the kelp forest is critically important to the nutrition of suspension feeders, which can make up >70% of animal biomass in the kelp forest (**Byrnes et al. 2011**). Stable isotope analyses revealed the composition of suspended POM varied considerably along a 3 km transect running perpendicular to (cross-shelf) and offshore of the Mohawk kelp forest (Miller and Page unpublished data) and that kelp forest suspension feeders primarily consume POM dominated by phytoplankton produced on the inner-shelf (Page et al. 2008). These results suggest that in regions with a narrow continental shelf such as California, cross-shelf processes have a large effect on the supply and export of key resources to and from the kelp forest. These findings motivate new research on the cross-shelf transport and fate of phytoplankton production in the Santa Barbara Channel, which is the topic of THEME 3C of our proposed research.

Nitrogen and carbon also flow from the kelp forest to intertidal communities at the land-sea margin. We have shown that detached kelp forest macrophytes (primarily giant kelp) constitute an important carbon and nitrogen subsidy to sandy beach communities in southern California (Dugan et al. 2003, 2008, Lastra et al. 2008). More recently, we found that concentrations of dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON) in intertidal porewater varied 1000 fold among beaches and were positively related to the accumulated biomass of macroalgal wrack (**Dugan et al. 2011)**. Surf zone concentrations of DIN were also related to wrack biomass and intertidal porewater DIN in late summer, when terrestrial groundwater and stream inputs were very low. These results suggest that the abundant kelp detritus on beaches is subsequently re-mineralized in intertidal sands to produce high concentrations of DIN that are exported seaward where it becomes available to nearshore primary producers (Proposed Research THEME 2C).

2. The direct effects of key environmental drivers on kelp forest community structure and function

Climate-induced changes in the supply of nutrients, disturbance from storm waves, and fishing of herbivores (e.g., sea urchins) and the predators that consume herbivores (e.g., lobster) are considered key drivers influencing giant kelp biomass and NPP, which in turn have profound effects on the structure and function of the kelp forest community (Foster and Schiel 1985, Graham et al. 2007). As part of our long-term monitoring we measure biomass, growth (defined as the amount of new kelp mass produced per unit of existing kelp mass per unit time) and NPP (defined as the amount of new kelp mass produced per unit area of ocean bottom per unit time) of giant kelp monthly at three kelp forests in the Santa Barbara Channel (detailed methods in Rassweiler et al. 2008). Using these data we showed that the amount of kelp biomass present at the beginning of the growth year explained 63% of the inter-annual variation observed in NPP, while the previous year's NPP and disturbance from waves collectively accounted for 80% of the inter-annual variation in biomass at the start of the growing season (Reed et al. 2008). Surprisingly, we found no correlation between annual growth rate and annual NPP, largely because annual growth rate was consistently high. Although growth rate was a poor predictor of variation in annual NPP, it was principally responsible for the high values observed for NPP (up to 4.4 kg dry mass m^{-2} y^{-1}). The high levels of NPP observed reflected rapid growth (~ 2% d^{-1}) of a relatively small standing crop (annual average = 444 g dry mass m^{-2}) that replaced itself about six times per year. The fate of this high productivity and its role in elemental cycling and food web dynamics in kelp forests and adjacent ecosystems are poorly understood and are research foci of THEME 1B of our proposed research.

Our observation of continuously high nitrogen content in kelp (generally above 1%) indicates that the input of nitrogen from oceanic and terrestrial sources is generally sufficient to maintain high growth rates (Reed et al. 2008). 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 (Dayton and Tegner 1989). Our results highlight 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, which we will examine further in SBC III (Proposed Research THEME 1A).

We determined the relative importance of different sources of nitrate to the annual nitrogen needs of giant kelp by combining our monthly in situ estimates of kelp NPP with high frequency data of nitrate supply provided by moored sensors (**Fram et al. 2008**). We found that the forest's monthly nitrate supply varied by a factor of 50, while our measured values of net nitrogen uptake varied only fivefold. An important, but unexpected, finding was that modeled gross nitrogen uptake with consideration of Michaelis–Menten kinetics for nitrate and mass transfer limitation was insufficient to account for the observed nitrogen utilization by giant kelp during the warm stratified summer and autumn months (June-November). This shortfall indicates that the kelp forest received over half its nitrogen from sources other than nitrate (such as ammonium) during the summer and fall, and it motivates new studies aimed at identifying these potential nitrogen sources (Proposed Research THEMES 2C and 3B).

We took advantage of regional differences in environmental forcing and consumer abundance to examine the relative importance of nutrient availability (bottom-up), grazing pressure (top-down), and storm waves (disturbance) in determining the standing biomass and

NPP of giant kelp in central and southern California (**Reed et al. 2011**). We found that despite high densities of sea urchin grazers and prolonged periods of low nitrate availability in southern California, giant kelp biomass and NPP were twice that of central California where nutrient concentrations were consistently high and sea urchin grazers were nearly absent due to predation by sea otters. Waves associated with winter storms were consistently higher in central California and the loss of kelp to winter wave disturbance was on average twice that of southern California. These observations suggest that the more intense wave disturbance in central California limited NPP by giant kelp during conditions that were otherwise favorable for growth and survival. Our findings provide strong evidence that regional differences in wave disturbance can overwhelm those in nutrient supply and grazing intensity to determine regional patterns of NPP by giant kelp.

Limits to the spatial extent of data that can be practically collected by divers led us to search for additional means of investigating regional patterns in kelp biomass and NPP. To this end we developed a novel method for estimating the canopy biomass of giant kelp from Landsat 5 Thematic Mapper satellite imagery, which we calibrated to that measured by divers in our long-term kelp NPP plots (**Cavanaugh et al. 2011**). The resulting data set derived from Landsat imagery enables us to examine the dynamics of giant kelp throughout California and Baja Mexico at spatial scales ranging from 90 m^2 to 100s of km^2 and temporal scales ranging from several weeks to > 25 years. Our analyses of these data revealed that winter losses of regional kelp canopy biomass in the Santa Barbara Channel were positively correlated with significant wave height, while spring recoveries were negatively correlated with sea surface temperature (which is often used as an inverse proxy for nutrient availability). Regional biomass lagged the variations in wave heights, sea surface temperatures, and the North Pacific Gyre Oscillation index by 3 y, indicating that these factors affect cycles of kelp growth and mortality. These results depict a high level of regional heterogeneity in the biomass dynamics of this important foundation species. We will make use of the unprecedented spatial and temporal resolution and extent of our newly developed kelp Landsat data in combination with other time series data to further our understanding of the roles of various abiotic and biotic drivers of kelp forest community dynamics (Proposed Research THEME 1A).

In response to the implementation of no-take Marine Reserves at the Santa Barbara Channel Islands, SBC researchers formed a unique collaboration with fishermen to investigate the effects of fishing on populations of spiny lobster (an important kelp forest predator) and on the structure of kelp forest communities. Collaborative trapping by SBC researchers and fishermen inside and away from reserves at the Channel Islands revealed decreasing gradients in lobster abundance and size with distance from the center of the reserve (**Kay et al. in press)**. The differences observed for legal-sized lobsters were driven primarily by reserve effects and the gradients near reserve borders were caused by net emigration of lobsters (*spillover*) from reserves into fished areas. Along the heavily fished mainland coast, analyses of lobster catch data provided by fishermen combined with sea urchin (lobster prey) and macroalgal (sea urchin prey) abundance data collected at our long-term kelp forest sites suggested that, contrary to previous reports (Lafferty 2004), lobster fishing did not lead to a general reduction in macroalgal abundance via a release in predation of sea urchins by lobster (Guenther 2010). The general importance of such trophic cascades in kelp forests (e.g., lobster –urchins—algae) and the role of fishing in triggering them continues to be the subject of much debate (**Reed et al. 2011**) and will be further examined in SBC III (Proposed Research THEME 1C)

3. The indirect effects of environmental drivers on kelp forest community structure and function and the feedbacks between structure and function

Giant kelp is considered a foundation species that not only provides food and shelter for a diverse array of species, but also alters the physical environment in which it lives. Environmental drivers that directly alter the abundance of giant kelp (e.g., large waves, nutrient delivery, episodic grazing) can have cascading indirect effects on the structure and function of the kelp forest community. Results of analyses combining kelp removal experiments with our long-term data on kelp forest community dynamics revealed 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 by shading understory algae (Arkema et al. 2009). Such interactions have implications for higher trophic levels as the composition of understory algae alters the abundance of prey for reef fishes (Schmitt and Holbrook 1990, Holbrook et al. 1990), which in turn determines the production and survival of young fish (Okamoto et al. in review).

We showed that giant kelp is more susceptible to removal by wave disturbance during large storms than are other components of the kelp forest community because larger drag forces act on it (Gaylord et al. 2008). Using structural equations modeling to link natural variation in wave disturbance with measured changes in food web structure at our long-term kelp forest sites we found that periodic removal of giant kelp by wave disturbance increased local species richness and the density of feeding links of food webs by both direct and indirect pathways (**Byrnes et al. 2011**). Predictions from statistical simulations agreed with results from a multi-year kelp removal experiment designed to simulate frequent large storms; both suggested that if large storms remain at their current annual frequency (roughly 1 major kelp-removing storm every 3.5 years), then periodic storms help maintain the complexity of kelp forest food webs. However, if large storms increase in annual frequency and begin to occur year after year, then kelp forest food webs will become less diverse and complex as species go locally extinct. The loss of complexity occurs primarily due to decreases in the diversity and complexity of higher trophic levels. Climate records for the Eastern Pacific show that the annual frequency of years with large winter storm waves has increased over the last 60 years (Graham and Diaz 2001, Ruggiero et al. 2010). Our findings demonstrate that shifts in climate-driven disturbances that affect foundation species like giant kelp are likely to have impacts that cascade through entire ecosystems.

To examine the indirect effects of wave disturbance on the partitioning of NPP among different groups of kelp forest producers, we developed in situ methods for measuring NPP by understory algae using benthic incubation chambers (Miller et al. 2009). This enabled us to compare rates of NPP by understory macroalgae with those by phytoplankton and giant kelp in areas where giant kelp was either experimentally removed or left in place (**Miller et al. 2011**). We found that the giant kelp canopy suppressed production by phytoplankton and understory algae. However, in the absence of giant kelp, NPP by phytoplankton and an established understory was comparable to that of the control plot where giant kelp was left intact.

The use of benthic incubation chambers has allowed us to investigate the contribution of understory algae to the productivity of the kelp forest ecosystem. However, logistical constraints render chambers less useful for longer-term studies and experiments, which are needed to understand the patterns, controls and ecological consequences of primary production by macroalgae. To overcome this problem we developed a simple physiologically-based model of benthic macroalgal production using three components: (1) bottom irradiance obtained from photosynthetically active radiation (PAR) sensors mounted to the sea floor, (2) taxon-specific photosynthesis versus irradiance (P vs. E) relationships measured in the laboratory for 19 taxa that comprise 97% of the macroalgal biomass at our study sites, and (3) taxon-specific methods for estimating biomass from non-destructive field measurements using morphological relationships (Miller et al. 2012). To test the model we compared its predicted estimates of production to measured estimates obtained with the benthic chambers deployed in situ and found a near 1-to-1 correspondence. We then applied this model to data collected in our long-term kelp removal experiment to investigate the extent to which increases in mortality rates of giant kelp (an expected consequence of increased storm intensity) lead to changes in ecosystem NPP and food web structure. The results revealed that, when measured in the summer, biomass alone is a good predictor of annual NPP by understory algae (Harrer et al. in review), which matches our findings for giant kelp (Reed et al. 2009). The development of these relationships and their application to long-term community data were made possible through sustained LTER funding and uniquely positions us to address a number of topical issues pertaining to community structure and function at spatial and temporal scales that are unprecedented for benthic marine systems (Proposed Research THEME 1A).

BROADER IMPACTS AND THE RESULTS OF SUPPLEMENTAL SUPPORT

The research platform provided by our project extends well beyond that supported by core LTER funding. SBC has been an active collaborator on 36 projects funded by 13 agencies totaling more than $18,000,000 during the first 5 years of our current award. SBC investigators are very active in applying their knowledge of coastal ecosystems to inform and implement changes in local and regional policies. We serve as advisors and committee members for a number of local and national groups concerned with conservation and management of natural resources as detailed in our Annual Reports http://sbc.lternet.edu/external/Documents/Progress_Reports/2006award/Annual_Reports/.

Supplemental funding for our Schoolyard LTER (SLTER) program targets K-12 students and teachers and is organized around a theme of watershed and marine ecology that incorporates SBC research. By partnering with the REEF (UCSB's educational marine aquarium facility) we have reached over 42,000 students and the general public since 2006. During 2006-2008, we worked with the Los Angeles Conservation Corps Clean and Green Program to deliver SBC content and education to 240 students and their families. Since then we have worked with over 400 Junior High School girls in collaboration with Tech Trek, a math/science summer program designed to develop interest and self-confidence in young women. Highlights from these programs include an 84-95% increased interest in attending college and an 18% increase from pre-test to post-test scores on curricula-based material. SBC makes a substantial contribution to education and training at the university level as well. Fourteen post docs, 54 graduate students, 12 REU students and more than 225 undergraduate students participated in our project's research and education activities during the first five years of SBC II.

Our contributions to human resource development extend beyond that of our project's participants and K-12 students and educators. With supplemental funding from an NSF Research Opportunity Award we are collaborating with students and faculty from Chapman University to examine potential ecological consequences of implementing Marine Protected Areas on rocky reefs throughout California. We also obtained supplemental funding to host the Ecological Society of America's SEEDS field trip, which allows under represented college students to explore their interests and career options in ecology through hands-on experience with professionals. The 3-day event attracted 22 students from 19 universities in the US and Puerto Rico who participated in field trips to local watersheds, intertidal habitats and offshore kelp forests led by SBC investigators and graduate students. Together with MCR LTER, SBC worked with Dreams Come True of Louisiana (a nonprofit organization that fulfills dreams for children with life-threatening illnesses) to help fulfill the wish of a high school student diagnosed with a rare form of cancer whose dream is to become a marine biologist. We also hosted visiting graduate students from the University of Bologna, Italy, and the University of Faro, Portugal to work on SBC related research. In return, we used funding from an OISE supplement to support SBC grad student Laura Carney to travel to the University of Algarve to work in the laboratory of Professor Ester Serrão on kelp genetics for a portion of her PhD dissertation.

Supplemental support was also used to purchase several equipment items that will be used in the research proposed for SBC III. These items include: (1) a buoyancy driven oceanographic glider and an ISUS chemical-free nitrate analyzer, which will be used to measure physical and chemical properties of runoff plumes, (2) deployable loggers equipped with a Honeywell Durafet® pH sensors for characterizing high frequency changes in ocean pH, and (3) a Ford Expedition for towing our 22 ft. research vessel.

SECTION 2 - PROPOSED RESEARCH

INTRODUCTION AND CONCEPTUAL FRAMEWORK

The exchange of materials across the boundaries of discrete ecosystems is ubiquitous and is an important determinant of many ecological patterns and processes (Valiela et al. 2001, Loreau et al. 2003, Knight et al. 2005, Massol et al. 2011). Understanding the extent to which ecosystems are connected and underlying mechanisms is also important because disturbances and environmental forcing occurring in one system can influence the ecological structure and function of another. Perhaps nowhere is this more evident than in coastal zones where nearshore marine ecosystems are intimately linked to the land and the sea. SBC strives to advance the basic understanding of such land-sea linkages in the semi-arid region of southern California where high levels of natural disturbance and human use combine with an ever changing climate to influence the region's biologically diverse, ecologically productive and economically valuable coastal ecosystems.

The major research objective of SBC is to develop a predictive understanding of how land and ocean processes alter the biological structure and ecological functions of giant kelp forests over the long-term under varying conditions of climate and human activities. Giant kelp (*Macrocystis pyrifera)* forests are highlighted in our research because they are prominent coastal ecosystems in California and other temperate regions of the world (Wormersley 1954, Graham et al. 2007). They are ecologically and economically very important because they provide food and shelter to a diverse array of species, many of which have high economic value (Foster and Schiel 1985, Leet et al. 1992). Importantly, the dynamic nature of giant kelp forests, characterized by frequent disturbance and rapid regeneration (on the order of a few years), coupled with their high productivity and diverse food webs make them ideal systems for investigating many ecological patterns and processes that require decades to centuries to address in other ecosystems.

The amount of inorganic nutrients, organic matter, and sediments exchanged between kelp forests and the land and sea that adjoin them varies in response to changes in climate, ocean conditions and land use (Figure 4). Variation in the supply of these materials interacts with natural and human-caused disturbances to influence the abundance and species composition of the forest inhabitants, their ecological functions and the ecosystem services that they provide. Thus an important objective of the SBC is to understand how ecosystems at the land-sea margin in coastal California are linked through the exchange of materials. The overarching question motivating our proposed research in SBC III is:

How are the structure and function of kelp forests and their material exchange with adjacent land and ocean ecosystems altered by disturbance and climate?

To address this question we focus our proposed research around three general themes (Figure 4):

1) Biotic and abiotic drivers of kelp forest structure and function,
2) Material exchange at the land-ocean margin, and
3) Movement and fluxes of inorganic and organic matter in the coastal ocean.

Characteristics of the study system

SBC is ideally suited to examine connectivity between terrestrial and marine ecosystems and the extent to which it is altered by disturbance and climate. Our site is bounded by the Santa Ynez Mountains to the north, the Channel Islands to the south, Point Conception to the west, and the Santa Clara River to the east (Figure 1). The catchments draining into the Santa Barbara Channel offer a rich variety of watersheds including natural chaparral, grazed and cultivated lands, and suburban and urban development. The east-west orientation of the coastline, narrow continental shelf and deep Santa Barbara Basin in the center of the Channel contribute to complex circulation patterns that result in a variable temperature and nutrient regime with relatively cold nutrient-rich waters in the western channel and relatively warm nutrient–poor waters to the east (Hickey 1992, Hendershott and Winant 1996, Harms and Winant 1998). The

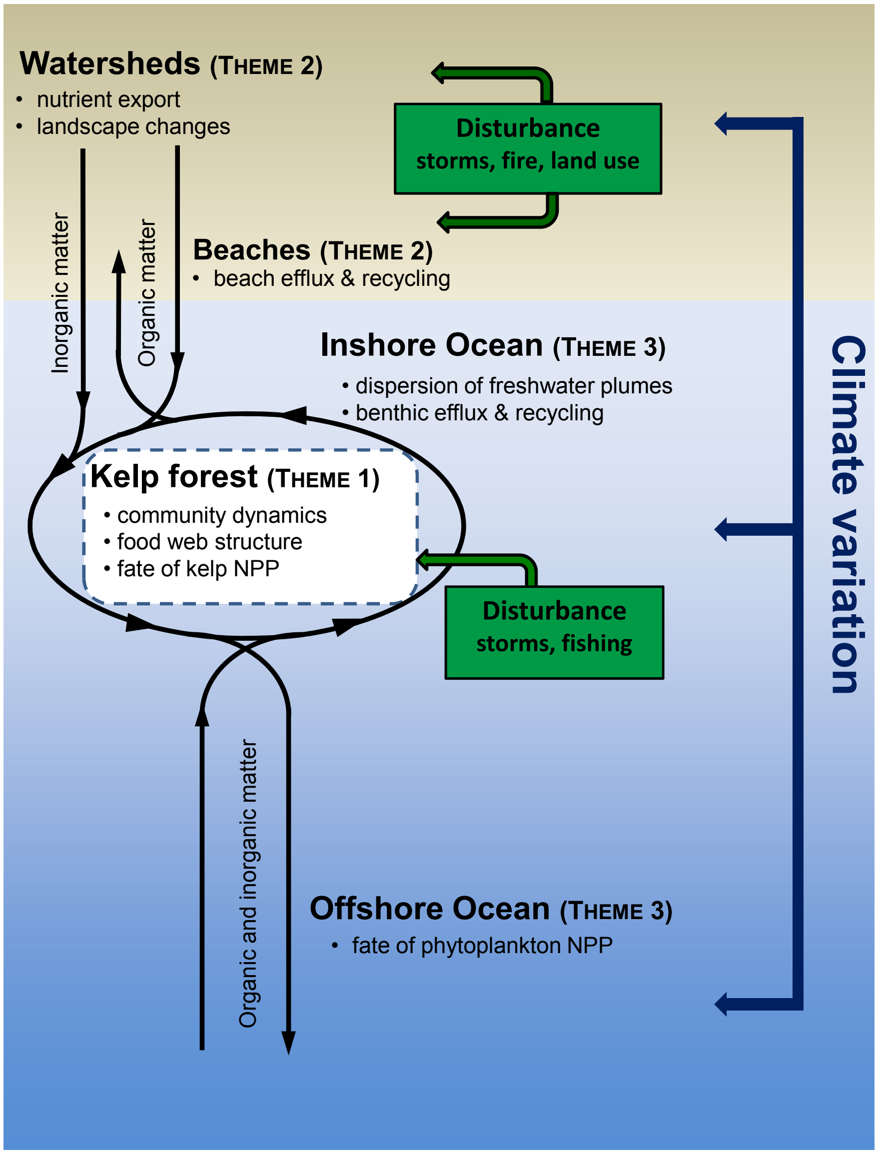

Figure 4. Conceptual framework for SBC III illustrating how the three research themes are integrated to address the overarching question "How are the structure and function of kelp forests and their material exchange with adjacent land and ocean ecosystems altered by disturbance and climate? Black arrows indicate the movement of organic and inorganic materials within and between land and ocean ecosystems.

Mediterranean-like climate of the region is characterized by calm, dry conditions in summer and autumn, prevailing northwesterly winds in the spring and episodic rainstorms in the winter. Climatic signals such as El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) are prominent in our study domain and greatly influence a wide variety of biogeochemical and ecological processes occurring on land and in the ocean. The relative and absolute contributions of different routes of nitrogen and carbon delivery to kelp forests during El Niño and La Niña years almost certainly varies with the state of longer-term (e.g., decadal scale) climatic oscillations associated with the PDO and NPGO. This environmental setting creates strong seasonality and high inter-annual variability in bottom-up forcing (via the supply of nitrogen) and physical disturbance (via waves from winter storms) in giant kelp forests (**Cavanaugh et al. 2011**).

Kelp forest communities are characterized by a trophic structure that is unique to intertidal and shallow subtidal reef ecosystems in that the primary space holders (i.e., macroalgae and sessile suspension feeding invertebrates) occupy different trophic levels (Figure 5). Macroalgae are primary producers that derive their nutrition from sunlight and dissolved nutrients, whereas sessile invertebrates are consumers that are nourished by filtering plankton from the water column. This trophic structure leads to two different pathways in the kelp forest food web: one

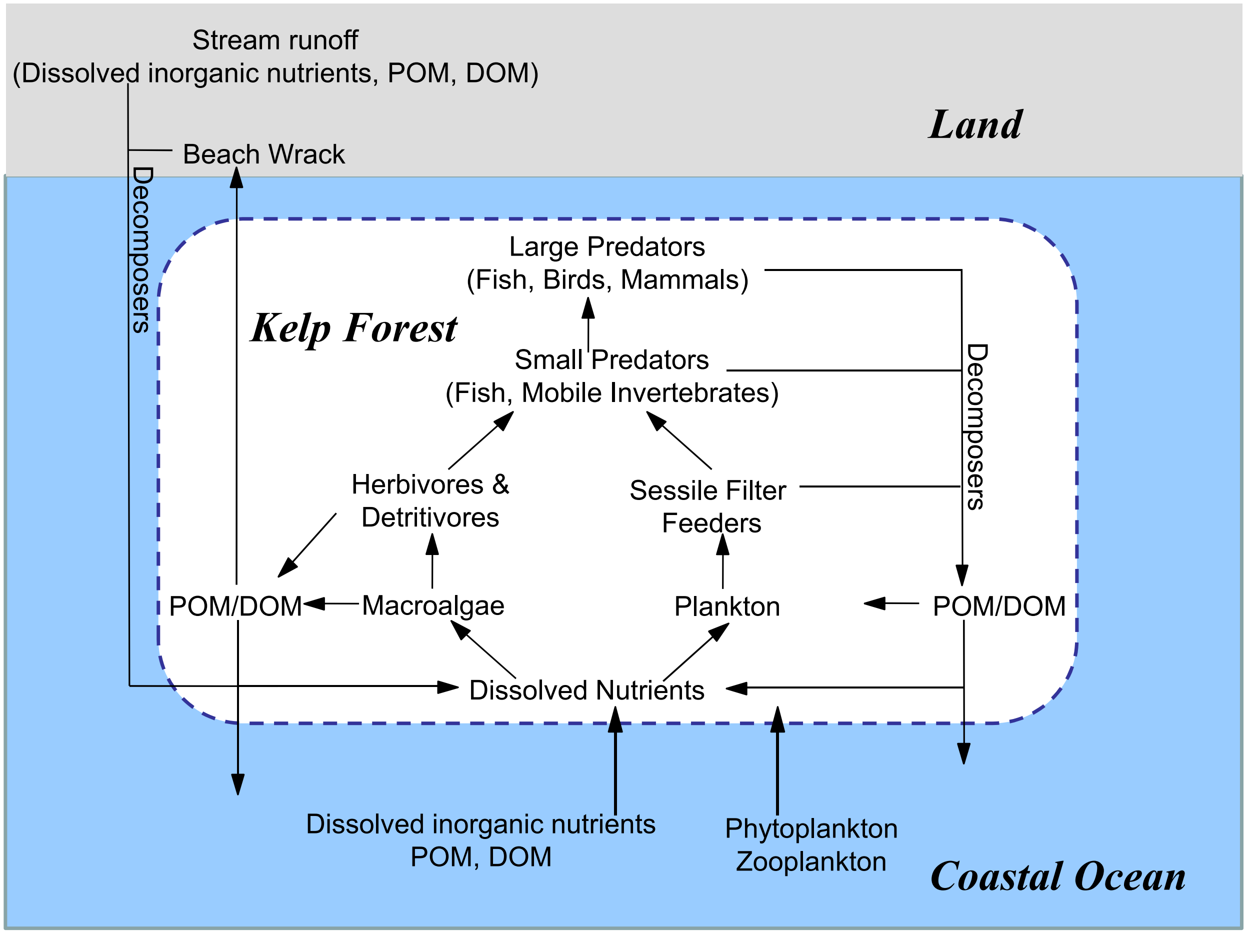

Figure 5. Simplified kelp forest food web showing the two pathways of primary production involving benthic macroalgae and phytoplankton. Macroalgae and sessile filter feeders occupy different trophic levels in the kelp forest yet compete for space on the bottom. The foodweb is subsidized by materials produced on land and in the surrounding coastal ocean.

derived from primary production by benthic algae and the other from primary production by phytoplankton in the water column. The supply of nitrogen is critical for both of these pathways (Jackson 1977, Eppley et al. 1979).

Kelp forests are considered to be relatively "open systems" with respect to nutrient dynamics in that the delivery and export of nitrogen into and out of the forest is thought to be far greater than the nitrogen supplied via recycling within the forest. Like many macroalgae, giant kelp has a limited capacity to store nitrogen (it can sustain growth for only 2-3 weeks in the absence of a significant external nitrogen supply, Gerard 1982) and because it grows on rocky substrata it does not have direct access to nitrogen stored in soils. Thus the high rates of sustained growth in giant kelp that we have observed (Reed et al. 2008, Stewart et al. 2009) rely on nitrogen subsidies supplied throughout the year from adjacent ecosystems.

The various types of nitrogen subsidies in this system are delivered seasonally. The largest ocean signal for nitrogen in our study domain is derived from wind-driven upwelling, which supplies cool, nutrient-rich water to kelp forests primarily during spring (McPhee-Shaw et al. 2007, **Fram et al. 2008**). Precipitation in the region is generally confined to late fall and winter when concentrations of ocean-derived nitrogen tend to be low. During this time of year, streams and rivers are capable of delivering substantial amounts of dissolved and particulate nitrogen to shallow coastal waters, particularly in areas adjacent to catchments where agriculture and/or urban development are the predominant land uses (Robinson 2006, Beighley et al. 2003). Internal waves (Zimmerman and Kremer 1984, Lerczak et al. 2001), other less understood oceanographic processes such as coastal eddies (Bassin et al. 2005, Dong et al. 2009, Kim et al. 2011), and effluxes from beaches and bottom sediments (Swarzenski and Izbicki 2009, **Dugan et al. 2011**) supply nitrogen to otherwise depleted surface waters in summer and fall, and are likely important in enabling giant kelp to persist and grow year-round in most years.

The mid 1970s to 2000 were marked by a pronounced warm phase of the PDO that witnessed some of the most intense El Niño events on record. These events were characterized by unusually warm, nutrient poor ocean conditions and anomalously large wave events, which had severe consequences for giant kelp forest communities throughout much of their extended range in the eastern Pacific (Dayton and Tegner 1989). The considerable amount of research on the ecology and physiology of giant kelp forests done during this period shaped our understanding and perceptions of the biotic and abiotic processes that structure these systems. The end of the extreme climatic conditions that characterized this multi-decadal period coincided with the establishment of the SBC LTER, and we have made surprising discoveries about how differently the kelp forest functions under the current more moderate conditions. We anticipate that these moderate conditions will change with future shifts in the PDO, NPGO and other climate related phenomena. The long-term nature of our integrated measurements and experiments makes us uniquely placed to study the effects of such climatic alterations on coastal ecosystems bordering the land-ocean margin.

GENERAL APPROACH

Certain environmental drivers of kelp forest ecosystems are relatively easy to simulate (e.g., kelp removal by physical disturbance), 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 takes advantage of a variety of approaches that include: (1) coordinated long-term measurements of key environmental drivers and ecological response variables, (2) manipulative field experiments designed to isolate the causal mechanisms underlying the patterns observed in our long-term measurements, (3) shorter-term, measurement-intensive studies aimed at obtaining a mechanistic understanding of processes that cannot be isolated using manipulative experiments, and (4) integrated synthesis using models and analyses that allow for predictions beyond the spatial and temporal scope of our measurements, and help guide future directions of our research. Collectively, these elements provide a powerful basis for building a greater understanding of the influences of material exchange on the biological structure and ecological functions of kelp forests under ever changing conditions of disturbance and climate.

A major goal of SBC's long-term measurements and experiments is to unveil 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. Because kelp forests occur at the land-sea margin, we collect long-term measurements on land, in the intertidal fringe, offshore ocean, and in the shallow inshore waters where kelp forests occur (Table 1). Importantly, our long-term measurements and experiments address all five of the LTER Network's core research areas, which form the cornerstone of LTER science. The integrated time series data that we are amassing on kelp forest community structure and ecological function, patterns and rates of biogeochemical inputs from the adjoining land, beach and ocean environments and the physical processes that drive them are unmatched for kelp forest ecosystems, and they make the SBC domain an attractive area for synthetic coastal ecosystem research. In SBC III we will be adding ocean pH to our long-term measurements as part of a coordinated cross-site comparison with MCR, CCE and PAL (Hofmann et al. 2011). High temporal resolution measurements of ocean pH in vastly different ecosystems are needed to develop a predictive understanding of the susceptibility of marine species to future anthropogenic ocean acidification. We will also add measurements of ^{15}N-enrichment in benthic kelp forest consumers and hydrogen isotopic analyses of nearshore sediments to track the fate of terrestrial organic matter entering the ocean. Hydrogen isotopes will track incorporation of terrestrial organic matter into sediments where they can be remineralized and released to waters advecting through kelp forests. Time series of consumer $\delta^{15}N$ coupled to proposed studies of terrestrial outflows, plume dynamics and nearshore circulation will track the incorporation of terrestrial POM into kelp forests. The sustained funding provided through the LTER program enables experimental manipulations to be continued over the long term. We embraced this opportunity in SBC II by initiating a long-term kelp removal experiment to evaluate prolonged changes in wave disturbance. We will be starting a new long-term experiment in SBC III to evaluate the effects of fishing on kelp forest communities (THEME 1C).

RESEARCH THEMES

THEME 1. Biotic and abiotic drivers of kelp forest structure and function

Wave disturbance from storms preferentially removes giant kelp, which affects the kelp forest community by altering the physical structure provided by the forest's foundation species (Arkema et al. 2009, **Byrnes et al. 2011**; THEME 1A, Figure 6). Disturbance from storms also acts to reduce kelp NPP (**Reed et al**. 2008, **2011**), which may indirectly feed back to alter the structure of the forest community by reducing the amount of organic matter available to kelp forest consumers and decomposers (THEME 1B, Figure 6). Decreases in kelp NPP also reduce the amount of kelp available for export to adjacent ecosystems (e.g. beaches) that rely on kelp subsidies. Unlike wave disturbance, fishing in giant kelp forests preferentially targets higher trophic levels (Jackson et al. 2001, **Kay et al. in press**) and thus has the potential to exert strong top-down control on the kelp forest food web (THEME 1C, Figure 6). All of these interactions are affected by variations in climate that alter the supply of organic and inorganic matter to kelp forests. Our proposed research will use data from long-term monitoring and experiments and shorter-term process studies to examine the general question:

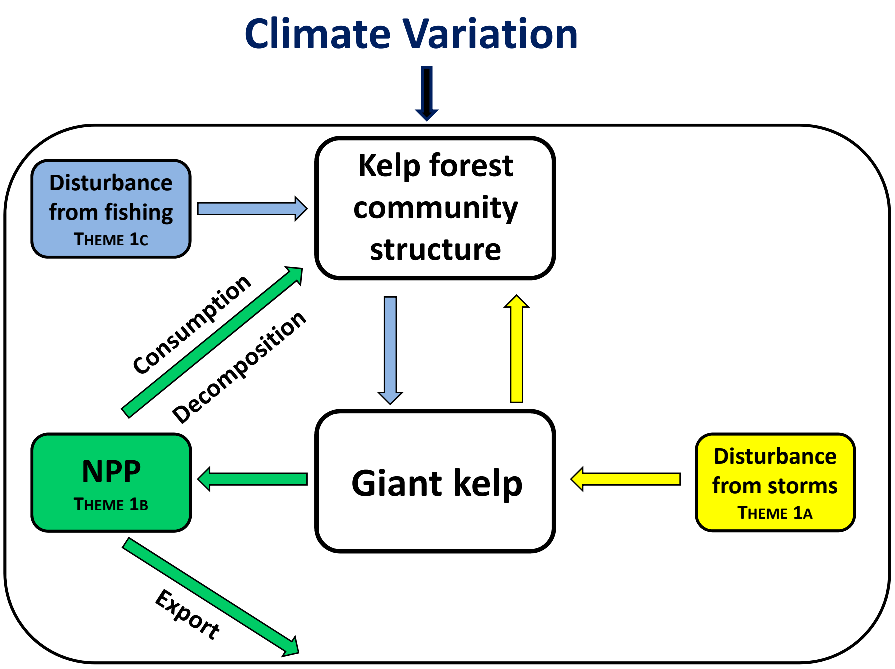

Figure 6. Conceptual diagram illustrating the influences of climate, storm disturbance and fishing on the structure and productivity of the kelp forest community.

How do variations in climate, wave disturbance and fishing influence the structure and dynamics of kelp forest communities and the fate of kelp NPP?

THEME 1A. Effects of wave disturbance on kelp forest structure and function

<u>Long-term kelp removal experiment:</u> One of the more evident aspects of climate change in California has been an increase in frequency and intensity of winter storms that produce large waves (Graham and Diaz 2001, Ruggiero et al. 2010), which are known to disproportionately

reduce the abundance of giant kelp relative to other components of the kelp forest community (Dayton and Tegner 1984, Dayton et al. 1999, Gaylord et al. 2008). To examine the potential consequences of an increase in the frequency of wave disturbance on kelp forest communities we initiated a kelp removal experiment in 2008 that we intend to maintain over the duration of SBC III. The experiment consists of removing giant kelp from permanent 40 m x 40 m plots at 5 of our core study sites (Carpinteria, Mohawk, Isla Vista, Naples, and Arroyo Quemado) once per year in winter. Adjacent undisturbed 40 m x 40 m plots at each site serve as controls. Community structure (i.e., the abundance and diversity of algae, invertebrates and fish) and various ecosystem processes (e.g., macroalgal NPP, kelp recruitment, detrital accumulation) are sampled twice per season. Data on ocean temperature and bottom and surface irradiance are obtained from sensors mounted in each plot; data on other physical/chemical variables (e.g., currents, conductivity, nutrients, chlorophyll, POM) are collected as part of our core ocean monitoring. These plots have already proven very useful for embedding shorter term experiments (**Miller et al. 2011**, **Byrnes et al. 2011**, Byrnes et al. in review) that rely on frequent sampling of the diverse benthic assemblages created by our manipulation of giant kelp, and the inherent variability in species composition and oceanographic characteristics of the 5 sites. Importantly, this experiment figures prominently in our synthetic analyses described below. The data are also contributing to a cross-site synthesis of long-term experiments conducted at 9 sites in the LTER Network to test emerging hypotheses pertaining to the relative vulnerability of different types of ecosystems to climate change (Smith et al. 2009, Knapp et al. in press).

<u>Synthetic analyses of long-term data</u>: As we continue to collect physical and biological data from our long-term study sites and kelp removal experiment, they become increasingly useful for examining general ecological processes that structure giant kelp forests, including the effects of wave disturbance and climate induced changes in physical, chemical and biological conditions. Moreover, the relationships that we developed from intensive sampling of our kelp removal experiment and kelp NPP plots (Reed et al. 2009, Miller et al. 2012, Harrer et al. in review, and unpublished data) allow us to estimate producer and consumer biomass and NPP from abundance data collected at our less frequently sampled (i.e., annual), but more temporally and spatially extensive (11 sites since 2000) kelp forest sites. These estimates of biomass and NPP will be incorporated into comprehensive data sets that we will use to investigate key processes governing the structure and function of nearshore reef communities across a wide range of environmental conditions. These investigations will be greatly facilitated by our ability to convert disparate measures of species abundance (e.g., percent cover and count data) into a single common metric of biomass density (expressed as ash-free dry mass per unit area) for all taxa that we sample in the kelp forest food web. Issues of general ecological interest that we plan to explore with these data sets include: (1) the ability of subordinate primary producers to compensate for the reduction in NPP following the loss of dominant species, (2) effects of diversity (richness, evenness and H') and species composition on spatial and temporal variation in NPP, (3) the relationship between food web stability (i.e., structural similarity through time) and species diversity, and (4) trophic characteristics of the simplified food webs that arise from increased wave disturbance.

To better understand how kelp forests respond to wave disturbance and other environmental forcings we are partnering with the Bureau of Ocean Energy Management, National Park Service and the US Geological Survey to incorporate their long-term (30+ years) data on kelp forest communities at the Channel Islands into our analyses of community dynamics. These data, which span the warm phase of the PDO and the severe El Niños of the 1980s and 1990s, have not been combined to provide a region-wide perspective. With collaborative funding from the Department of Interior we are assimilating these data with similar ecological data collected by SBC, Landsat-derived giant kelp abundance and data describing likely sources of climatic variation and disturbance (e.g. NPGO, PDO and ENSO state, wave disturbance history). This new integrated regional data set will be particularly helpful for our understanding of sudden changes in community state (e.g., a shift in dominance from macroalgae to sessile suspension feeders or from a densely vegetated reef to an non-vegetated sea urchin barren), which are characteristic of rocky reefs in southern California and elsewhere (Harrold and Pearse 1987, Petratis and Dudgeon 2005, Rassweiler et al. 2010). The phenomenon of abrupt shifts in community state is a topic that the LTER Network is unusually well placed to address and we recently participated in cross-site analyses with researchers from five LTER sites to develop improved methods for detecting such shifts (Bestelmeyer et al. 2011). The regional data set we are assembling will greatly increase our ability to understand the nature of these shifts. It will also add decades to the temporal reach of our analyses and more than double the area of study, giving us more shifts to examine across a broader region subjected to a wider range of environmental conditions. A number of methods have been proposed to use time series data to detect threshold levels of shifts in community state, and even to infer whether such shifts are examples of hysteresis (Rassweiler et al. 2010, Smith 2011, Bestelmeyer et al. 2011). The regional data set we propose to integrate will provide an excellent opportunity to test these methods.

Metapopulation modeling of giant kelp: We have shown that giant kelp in the Southern California Bight can be viewed as a metapopulation of discrete patches that grow and decline asynchronously and are connected via dispersal that allows local populations to be rescued following local extinction and to recover rapidly following disturbance from waves (Reed et al. 2006). Our recent compilation of a 27+ year data set on kelp patch dynamics obtained from Landsat imagery (**Cavanaugh et al. 2011**) coupled with our development of methods for estimating oceanographic connectivity from a high resolution Regional Ocean Modeling System (ROMS) for the Southern California Bight (Dong et al. 2009, Mitarai et al. 2009) provide us with an unprecedented opportunity to assess and model the metapopulation structure of this key habitat forming species throughout its distribution in southern California and Baja Mexico.

Not only are the Landsat data ideal for characterizing the spatio-temporal dynamics of local kelp populations, but they also can be used to estimate the number of adult individuals in a local population and the quantity of spores that they produce (Figure 6), thus allowing us to derive estimates of local population size and fecundity over time. ROMS output will be used to develop a connectivity matrix describing the dispersal pattern of kelp spores in the Southern California Bight for a range of oceanographic conditions (following the approach we have used in the Santa Barbara Channel, Alberto et al. 2011). Together, the spore production matrix generated from Landsat and the connectivity matrix produced by ROMS will form the foundation of our

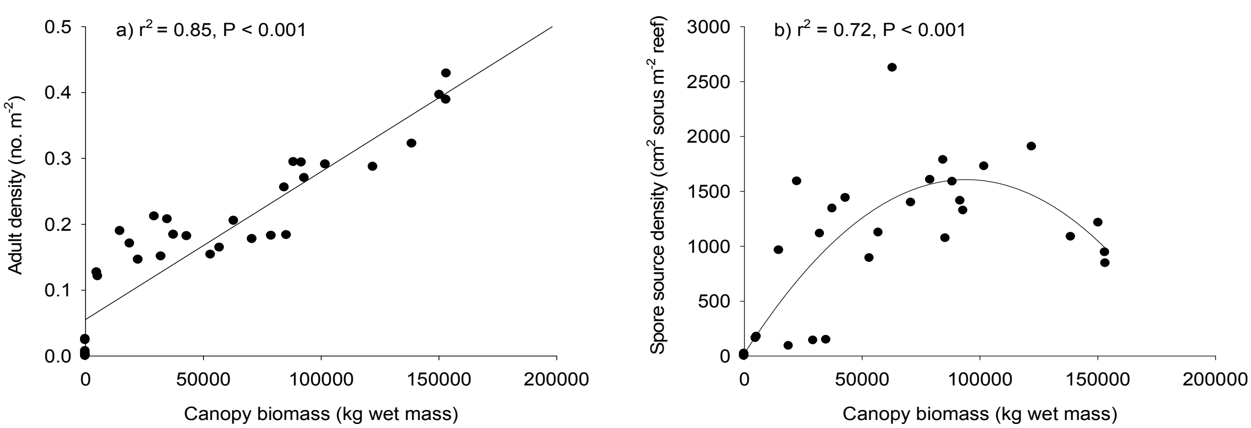

Figure 7. The relationship between kelp canopy biomass estimated from Landsat images and (a) adult kelp plant density and (b) kelp spore source density. Data on adult plant density and spore source density were collected by divers in long-term study plots.

metapopulation model. We will use this model to examine a variety of metapopulation characteristics including: (1) the relative importance of local populations to the regional pool of contributed spores, (2) the relative importance of local populations in rescuing neighboring populations under different oceanographic conditions, and (3) the response of metapopulation dynamics to different scenarios of climate change.

THEME 1B. Determining the fate of kelp NPP

NPP by giant kelp rivals that of the most productive ecosystems on Earth (Reed and Brzezinski 2009). Our high frequency (monthly), relatively long-term (ongoing since 2002) measurements have revealed not only high mean values of giant kelp NPP, but also tremendous spatial and temporal variation in NPP. Analyses of our multi-year, multi-site time series data coupled with satellite derived estimates of kelp biomass have led to a much improved understanding of the local and regional processes driving this high variability (**Reed et al.** 2008, **2011**, **Cavanaugh et al. 2011**). Organic matter produced by giant kelp can either be retained and remineralized within the kelp forest by forest dwelling consumers and decomposers, or it can be exported horizontally out of the kelp forest to adjacent beach and open ocean ecosystems. Determining the trophic role and fate of kelp NPP remains a challenge that must be addressed to evaluate the ecosystem consequences of high variability in NPP. To determine the proportion of kelp NPP that is retained and utilized in the kelp forest versus exported to other ecosystems we propose to: (1) quantify the amount of kelp NPP that is grazed by forest consumers, (2) quantify the different forms of kelp NPP available for export, and (3) determine the export ratio (carbon exported:NPP) for each form of kelp NPP.

Canopy-dwelling organisms are the main grazers of living kelp plants in the absence of large aggregations of grazing sea urchins, and losses to canopy grazing are thought to be small (Sala and Graham 2002). We will estimate these losses by measuring biomass-specific consumption rates of canopy grazers in the laboratory and extrapolating these rates to the field through monthly measurements of species-specific grazer biomass in the kelp canopy at our NPP sites.

NPP available for export can be categorized into two forms: (1) particulate organic matter (POM) that is derived from the standing biomass of kelp and (2) and suspended dissolved organic matter (DOM) that is released by kelp tissue. The particulate fraction of kelp NPP that is available for export is comprised of kelp particles ranging in size from entire plants, to plant fragments that fall to the bottom (i.e., litter), and smaller-sized fragments that remain suspended as POM. We measure the disappearance of entire plants as part of our long-term measurements of kelp NPP. We will deploy litter traps on the bottom at our NPP sites to measure the flux of large litter. Smaller litter traps (mesh bags) will be placed around individual blades in 24 hr deployments to estimate the carbon flux of smaller particulate litter, and bag incubations (similar to those we have used to measure DOM flux) will estimate suspended POM flux. Preliminary experiments have shown that this method works well, and that blade size and age are good predictors of POM losses (Yorke, Miller and Page unpublished data).

In field experiments we found that production and release of DOM by giant kelp is substantial (~30% of NPP). However, the fate of the kelp-derived DOM remains undetermined. We will conduct microbial remineralization experiments (Carlson et al. 2004) to estimate the rate of DOM drawdown by bacterioplankton. DOM remineralization rates will allow us to estimate the amount of kelp-derived DOM that is available for export. Direct export of material through the grazing pathway is likely negligible since the grazers are kelp forest residents. However, particulate forms of NPP may be converted to DOM by grazers and detritivores during feeding, which could become potentially available for export from the kelp forest. Microcosm experiments will be used to measure the production of DOM via the feeding of grazers and detritivores to estimate this potential export term.

The export of kelp production E_{total} (in units of C $m^{-2}d^{-1}$) can be described as the sum of the export carbon for each form of NPP available for export out of the boundaries of the kelp forest:

$$E_{total} = E_{plant} + E_{litter} + E_{POM} + E_{DOM}$$

We assume that all of the carbon associated with the disappearance of whole plants (E_{plant}) is exported out of the forest, a reasonable assumption given the high buoyancy of dislodged plants and the large drag forces that act on them. E_{litter}, E_{POM}, and E_{DOM} can be simply described as:

$$E = Ie^{-TC}$$

where I is amount of kelp NPP available for export as litter, suspended POM, or DOM that is measured using the approaches outlined above, T is residence time of litter, suspended POM, or DOM within the forest, and C is the rate of consumption or remineralization per unit time in the forest. Litter is consumed by detritivores and microbes on the seafloor. To quantify C_{litter} we will stake litter of different sizes to the bottom and measure consumption rates by detritivores. Decomposition rates of litter will be measured in litterbags fastened to the bottom that exclude macroscopic detritivores. We will estimate C_{POM} and C_{DOM} by measuring the rates of remineralization by heterotrophic bacterioplankton in laboratory experiments.

Residence time of litter in the forest will be estimated monthly by measuring accumulated litter on the seafloor and assuming steady state, whereby residence time will calculated as:

$$T = {}^{A}/_{I}$$

where A is the accumulated reservoir of litter and I is input of litter. Residence time of suspended material within the kelp forest will be calculated based on water mass residency times as per the methods of **Fram et al. (2008)**. The accumulation and remineralization of kelp litter exported to beaches will be investigated in THEME 2D of our Proposed Research.

THEME 1C. Effects of fishing on kelp forest structure and function

Although we have been aware of the potential importance of fishing on nearshore reef communities, it has not been possible to manipulate this factor in any of our previous experiments. However, the California Fish and Game Commission recently adopted regulations to create a network of marine protected areas (MPAs) in southern California (effective January 1, 2012) and we are fortunate that two of our long-term kelp forest study sites (Naples Reef and Isla Vista) are located within these newly created MPAs. This provides us with a unique opportunity to experimentally investigate the short and long-term effects of fishing on kelp forest structure and function, and to place those effects within the context of past variability. We will use our ongoing long-term kelp forest community data (collected annually since 2001) in a Before-After-Control-Impact-Paired (BACIP) design to compare the trajectories of community change in fished and non-fished sites after the establishment of the new MPAs. Because two of the MPA sites (Isla Vista and Naples Reef) also serve as sites in our long-term kelp removal experiment, we will be able to examine the interactive effects of fishing and wave disturbance (as simulated by experimental kelp removal) on community structure and ecosystem processes (such as NPP and detrital accumulation) on a seasonal basis. Importantly, we will be well poised to specifically address the effects of fishing on inducing trophic cascades in kelp forest food webs, which has been the subject of considerable debate (Jackson et al. 2001, Foster et al.2006, Halpern et al. 2006, Steele et al. 2006, Foster and Schiel 2010). These cascades have been proposed to be driven in southern California by fishing of spiny lobster and sheephead wrasse (Jackson et al. 2001, Lafferty 2004). Sheephead are readily counted in our current monitoring, but lobsters are largely nocturnal foragers and seek shelter in cryptic habitats during the day. Thus, we will supplement our daytime diver surveys of kelp forest community structure with night time surveys aimed at obtaining more accurate estimates of lobster abundance. Spatially explicit data on lobster catch and fishing effort at our fished sites will be provided by commercial fisherman as part of the CALobster collaborative fisheries research program involving UCSB researchers and commercial fishermen (http://www.calobster.org/). Collectively, these data will be used to examine the effects of fishing pressure in inducing a trophic cascade among lobster, sea urchins and macroalgae. Our intent is to leverage this research to obtain funding to develop parallel research programs that integrate ecology, social science, and management/systems science.

Specifically, we plan to test key questions related to human-resource interactions and adaptive management theory to: (1) study how individual fishermen, fishing fleets, and resource governance institutions respond to the multiple effects of MPAs, and (2) develop dynamical decision models that simulate how informed predictions about long-term ecological changes enhance management decisions made over the short-term.

THEME 2. Material exchanges at the land-ocean margin

Coastal watersheds, estuaries and beaches in southern California are subject to highly episodic environmental drivers, notably wildfires and strong winter storms that bring heavy rainfall and powerful waves that cause intense runoff and erosion. These newsworthy events represent the extreme end of a spectrum of more regular variations in the environment on scales of days, seasons, years, and decades, including the warm and cool phases of ENSO and the PDO.

The very large temporal and spatial variability in the fluxes of materials from land to the coastal ocean, as noted in Section 1, requires a multi-tiered research approach to capture the full range in the magnitude of fluxes and their responses to changes in climate, land cover and fires. Our prior analyses of the contribution of land-derived nutrients to kelp forest ecosystems considered only supply to and use of nitrate in kelp ecosystems in years with low amounts of terrestrial runoff (McPhee-Shaw et al. 2007, **Fram et al. 2008**). We now realize that concentrations of particulate and dissolved organic forms of nitrogen exceed nitrate, and that periods with large amounts of rainfall and years following fires result in fluxes many fold higher than previously considered (**Beighley et al. 2008**, Coombs 2006). As these inputs of terrestrially-derived particulates are mineralized in near-shore sediments they become a source of inorganic nitrogen to nearshore producers that is evident in the isotopic composition of kelp forest consumers (Page et al. 2008). Decomposition of organic matter within beach sands and regular exchanges of the resulting nutrient-rich porewaters are another additional source of nutrients to nearshore waters (**Dugan et al. 2011**). Hence, to understand how watersheds and coastal margins interact with nearshore waters and kelp forest ecosystems, and the processes that cause these interactions to fluctuate in time, we propose to address the general question:

> *How does the input of dissolved and particulate nutrients from watersheds and coastal margins to nearshore waters vary as a function of land use, disturbance by fire and storms, seasonality and longer-term climatic variations?*

THEME 2A Export of nutrients from watersheds

The export of nutrients from watersheds is a key component of material exchange between the land and the coastal ocean (Figure 4). We will continue to determine stream discharge and to measure concentrations and calculate fluxes of dissolved and particulate nutrients and organic matter in streams representing various land uses as part of our ongoing long-term measurements (Table 1). Because the wildfires that recently burned several watersheds represent major disturbances to the terrestrial environments and caused large increases in fluxes to nearshore waters, we will continue studies in these watersheds to follow changes in the export of nutrients as a function of vegetative regrowth and soil processes (as described below). In addition, we propose to use models to assess how climate variability influences hydrologic responses and associated nutrient fluxes over a range of time scales and fire frequency/severity scenarios. Successfully modeling solute and particulate export depends on understanding the interactions among land cover, land use, rainfall, plant and microbial activity, and soil properties. Our measurements of nutrient export, which now span a wide range of hydrologic conditions from a variety of burned and unburned landscapes, provide the basis for significant modifications to our existing export models (Melack and Leydecker 2005, Robinson 2006). Hence, we propose to develop multivariate statistical models and adapt existing mechanistic models to estimate hydrochemical fluxes from watersheds to the coastal waters of the Santa Barbara Channel (Figure 8).

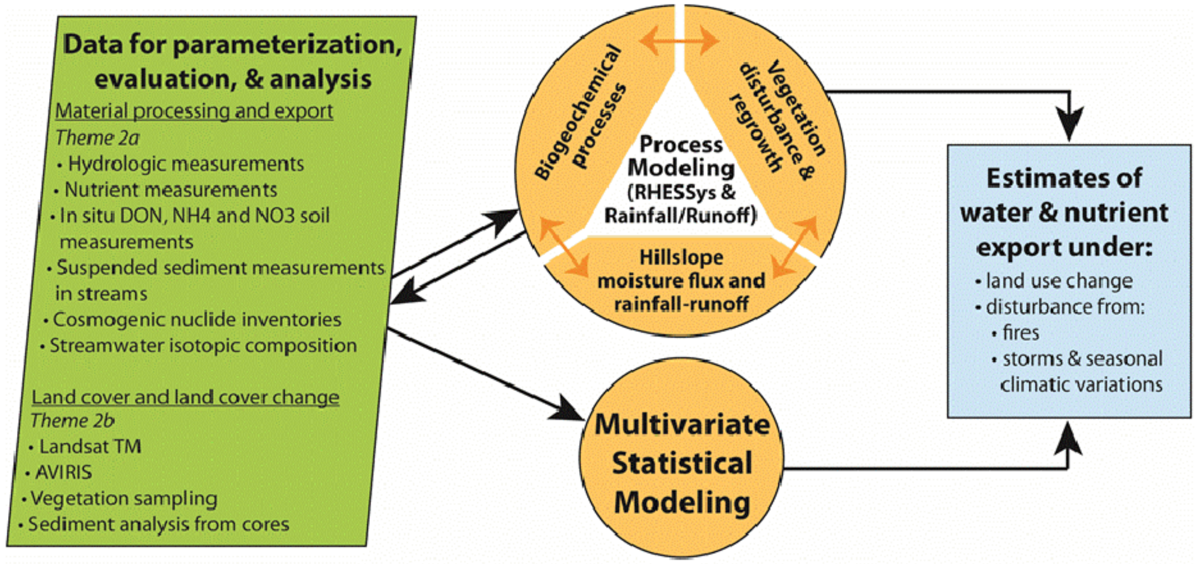

Figure 8. Schematic diagram showing how measurements and models will be integrated in THEME 2A and 2B to estimate material export from land to the coastal ocean.

Our modeling framework will combine and revise two models that we previously have applied to the study area. The first is a watershed scale (1-10 km^2) rainfall-runoff model (**Beighley et al**. 2005, **2008**, 2009) and the second is RHESSys, a finer-scale (0.01 km^2) hydro-ecological model that incorporates vegetation water-use, regrowth and hydrologic processes into simulations of carbon, water and nutrient fluxes (Tague and Band 2004, Tague et al. 2009). Our modeling approach links these two models and supports the assimilation of remote sensing data and field measurements for model parameterization and assessment (Figure 8). In particular, we will combine trajectories of vegetation change derived from remote sensing (developed in THEME 2B) with estimates of vegetation recovery following fire derived from the RHESSys carbon cycling model (using approaches similar to Williams et al. 2005). Nutrient export and isotopic composition measurements will be used to improve parameterization of nutrient source and sink processes. We will use several approaches to incorporate measurements of nitrogen transformations and movement in representative upland, suburban and agricultural areas into our modeling results using several approaches. These approaches will include: (1) production and consumption of DON, NH_4^+, and NO_3^- with a resin core technique; (2) installation of porous cup lysimeters to evaluate NO_3^- leaching; and (3) analysis of isotopic composition of the oxygen and nitrogen in NO_3^- in stream water to decipher the contribution of atmospheric deposition and microbial processes, as we have done elsewhere (Sickman et al. 2003).

Large fluxes of nutrients associated with sediments are controlled primarily by low frequency, large magnitude events such as storms and fires (Florsheim et al.1991, Warrick and Milliman 2003). We will continue our long-term measurements and analyses of concentrations and calculations of fluxes of suspended solids in streams (Table 1) to examine how episodic transport varies as a function of storm size, land use and fire. In order to measure short-term erosion rates and identify areas in which erosion is occurring, we will obtain additional airborne and ground-based lidar measurements to enhance the lidar data that we obtained soon after the recent fires (Perroy et al. 2010). Longer-term estimates of erosion will be obtained from cosmogenic nuclide inventories (Granger et al. 1996, Kirchner et al. 2001, Schaller et al. 2001, von Blanckenburg 2005), which will extend the time of our analyses beyond the period with direct measurements of sediment movement. This relatively new technique for estimating erosion works on the principle that long exposure times to cosmic rays result in high cosmogenic nuclide concentrations in river sands, and indicate low erosion rates, while low cosmogenic nuclide concentrations indicate a fast conversion from rock to soil and are characteristic of rapidly eroding landscape. The method averages the exposure time of in-situ rocks over multiple natural disturbances and provides flux estimates over hundreds to thousands of years. We have successfully used this technique in the past to capture rare high-impact events in our study region (Perroy et al. in press). River sands will be collected from streams in the Santa Barbara region, processed at UCSB and then sent to Lawrence Livermore National Lab or PRIME Lab (Purdue University) for accelerator mass spectrometry measurements.

THEME 2B. Trajectories of landscape changes in coastal watersheds

A significant aspect of material input to nearshore waters concerns how disturbance, in the form of fire, urbanization and agriculture, alters the landscape to modify these inputs. We will classify and map changes in land cover and characterize biophysical properties of the vegetation using a combination of high resolution aerial photography, satellite imagery (Landsat Thematic Mapper (TM)) and recent Landsat, Airborne Visible Infrared Imaging Spectrometry (AVIRIS) and airborne lidar data. Quantitative measures of changing surface composition will be determined using Landsat TM data from 1984 to the present. Recent changes, in response to wildfires that occurred in 2008 and 2009, will be examined using AVIRIS data acquired prior to the fires and on multiple dates following the 2008 Gap and Tea fires and the 2009 Jesusita fire.

Analysis of historical aerial photography will rely on photointerpretative and object-oriented classification approaches, leveraging prior research that has modeled urban growth in the region (Herold et al. 2005). Landsat analyses will rely on approaches such as spectral mixture analysis that we developed to analyze land cover change (Roberts et al. 1993, Roberts et al. 2002, Numata et al. 2010) and urbanization (Powell and Roberts 2010). Our analyses of AVIRIS data will include quantifying pre-fire fuel conditions, fire severity and monitoring post-fire recovery of biomass and plant nitrogen and water content. Species composition and land cover will be mapped using Multiple Endmember Spectral Mixture Analysis (MESMA: Roberts et al. 1998), and post-fire canopy biochemistry will be mapped using spectral fitting (Roberts et al. 1997) and partial least squares regression (Martin et al. 2008). Additional AVIRIS data are anticipated to be acquired through other sources (NASA funding in 2012 and 2013 and the NEON airborne observatory). On-the-ground measurements of terrestrial vegetation will aid interpretation of the remotely sensed information and will be used to assess rates and sources of variation in ecosystem recovery. These measurements will include peak growing season biomass via direct harvests, percent cover by species, leaf area index, and vegetation moisture and nitrogen content, and near surface (upper 20 cm) soil nitrogen pools.

We propose to extend the time scale of our examination of landscape changes by analyzing sediment cores collected from accumulated deposits in two estuaries (Goleta and Carpinteria) that border the Santa Barbara Channel. Cores and high-resolution seismic data will be used to reconstruct the shape and volume of the valleys excavated by the streams flowing into these two estuaries during the last eustatic fall in sea level. These reconstructed data will provide a record of sedimentation as a function of changes in climate and fire frequency through the Holocene. Approximately 10 cores up to 20 m in length will be collected from each estuary using a Geoprobe 7822DT. The relative percentages of fluvial, tidal basin and marsh sediments within the valley fill will be determined from these cores and a high-resolution record of extreme flooding (Troiani et al. 2011, Haberlah and McTainsh 2011) and fires (Mensing et al. 1999) will be reconstructed. Cores will be analyzed and interpreted based on grain size, sedimentary structures, macrofauna and microfauna (e.g., Shepard and Moore 1954, Simms et al. 2008). If well-developed fine-grained deposits are encountered, as previous studies suggest (Lohmar et al. 1980), then radiocarbon ages will be obtained from articulated mollusks and peats.

THEME 2C. Exchanges of nutrients on beaches

Kelp forests export large quantities of organic debris to adjacent ecosystems in response to wave action (Figures 4 and 5). Much of this material strands on sandy beaches as wrack (>500 kg $m^{-1} yr^{-1}$) creating an organic-rich environment on permeable sands subject to regular tides and waves. Once stranded on beaches, these large organic subsidies are subject to intense consumer and microbial activity (Lastra et al. 2008). This activity favors rapid remineralization that leads to accumulation of wrack-derived nitrogen and carbon in saline intertidal porewaters on beaches, which can subsequently be exported to nearshore waters (Figure 5). We have shown that the intertidal porewater of beaches along the Santa Barbara Channel can be suboxic and contain high concentrations of ammonium, nitrate, DOC, POC, DON, and PON (**Dugan et al. 2011**, B. Goodridge, unpublished data). The relationships we found between wrack inputs, porewater nutrients and beach erosion (**Dugan et al. 2011**, Revell et al. 2011) suggest that the accumulation of wrack-associated solutes in intertidal beach porewaters and their release to nearshore waters could be an important source of nitrogen to kelp forests and other shallow water primary producers during periods when upwelling and stream inflows are low. Open coast sandy beaches in other regions are active zones of biogeochemical transformation of groundwater-derived nutrients from upland sources, and can act as significant zones for transport of these nutrients to the coastal ocean (Burnett et al. 2003). The extent to which beaches export nutrients derived from the remineralization of macroalgal wrack is largely unknown.

To assess the degree to which beach ecosystems can supply recycled marine nutrients to nearshore waters, we will examine wrack inputs to beaches, wrack shredding by intertidal consumers and the biogeochemical processing and fate of macroalgal wrack and other sources of coastal POM in intertidal beach porewater. Our long-term measurements of inputs of kelp wrack to beaches in relation to kelp forest productivity will shed light on the magnitude, timing, sources, and relative importance of exchanges of materials between kelp forests, beaches and nearshore waters. Intertidal population surveys will quantify variation in the abundance of key intertidal wrack consumers (i.e., talitrid amphipods) and targeted experiments will quantify size and species-specific differences in their shredding and consumption rates. We will investigate the potential contribution of wrack to the intertidal porewater nitrogen pool by augmenting sand columns with wrack and/or invertebrate consumers. These experiments will allow us to determine: (1) the potential importance of shredding by intertidal invertebrate consumers to subsequent wrack nitrogen remineralization in intertidal porewater, and (2) the relative contribution of wrack nitrogen to intertidal porewater versus other PON and DON sources (e.g., marine DOM and POM, phytoplankton).

Seasonal, short-term deployments of piezometer transects over spring and neap tidal phases and nearshore radon-222 measurements will provide estimates of intertidal porewater flux to the nearshore ocean. Concurrent ^{15}N-labeled POM pulse-chase field studies and subsequent measurement of ^{15}N isotopic ratios in pore water and nearshore marine water pools (i.e., $DO^{15}N$, $^{15}NH_4^+$, $^{15}NO_3^-$, $^{15}N_2O$, and $^{15}N_2$) will allow a determination of key nitrogen biogeochemical pathways within intertidal pore water and nitrogen release to the nearshore ocean, elucidating the importance of intertidal pore water as a potential nitrogen source to the nearshore ocean.

Data on wrack inputs, consumer shredding and biogeochemical processing will be combined to estimate spatial and temporal patterns of nitrogen flux from beaches. The responses of intertidal ecosystems to subsidies of subtidal marine macrophytes with a focus on the processing and fate of imported organic matter may apply generally across many coastal regions, and we are working with scientists from VCR in developing comparative analyses on this topic.

THEME 3. Movement and fluxes of inorganic and organic matter in the coastal ocean

Giant kelp forests rely on the supply of exogenous nutrients and plankton to fuel their diverse and productive food web (Figure 5). A variety of complex physical processes acting in the coastal ocean determine the amount and timing of these materials delivered to kelp forests (Figure 9). Building upon the results of our prior research, we propose to use existing long-term data sets, new data collected from focused sampling, and modeling of coastal ocean circulation to investigate the general question:

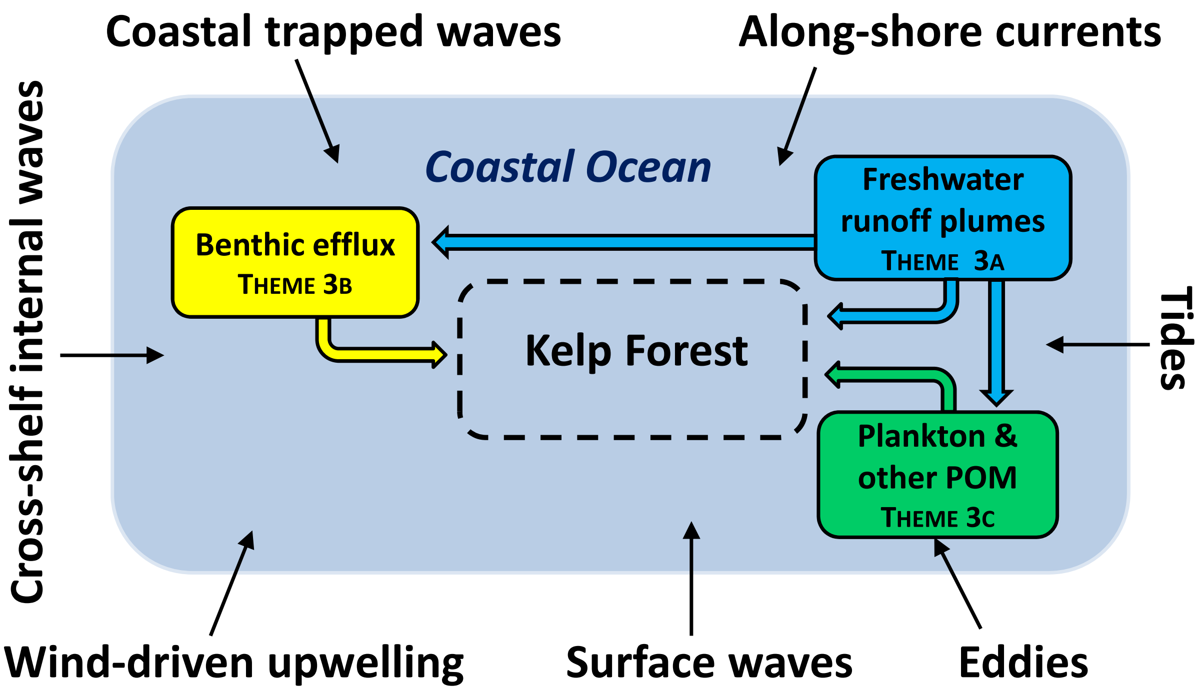

Figure 9. Conceptual diagram showing the various oceanographic processes acting on the coastal ocean that influence the amount and timing of inorganic and organic matter delivered to kelp forests by freshwater runoff plumes (THEME 3A), benthic efflux from sediments (THEME 3B) and phytoplankton net primary production (THEME 3C).

How do oceanographic processes act to influence: (a) the dilution and dispersal of freshwater runoff plumes, (b) nitrogen recycling and efflux from benthic sediments within and adjacent to kelp forests, and (c) the fate of net primary production by phytoplankton?

THEME 3A. Dilution and dispersal of freshwater runoff plumes

Runoff from coastal streams adds inorganic nutrients, organic matter, and sediments to the nearshore ocean and represents a portion of the nutrients supplied to kelp forest ecosystems (McPhee-Shaw et al. 2007, **Fram et al. 2008**, **Beighley et al. 2008**). Determining the fate of runoff in the nearshore ocean has been challenging because freshwater plumes are buoyant and form thin layers at the sea surface that are difficult to sample. Moreover, the intermittent nature of stream discharges in southern California and the short duration (typically a day or less) and timing (usually occur during rough seas and foul weather) of peak flows make them difficult to sample from small boats. Hence, we propose to characterize the processes of plume dilution and dispersal through a combination of high-resolution (~50 m) ocean circulation modeling and intensive observation of runoff events using propelled and buoyancy driven autonomous underwater vehicles, instruments deployed on moorings, and sampling from piers and small boats. Our approach will entail: (1) describing the flow structures (fronts, eddies, etc.) that control the offshore dispersion of runoff using the Regional Ocean Modeling System (ROMS; Shchepetkin and McWilliams 2005), (2) sampling individual storm events near stream outflows using autonomous and moored instruments, (3) validating models of plume dilution with field observations and modifying the models as needed, and (4) parameterizing the dilution of freshwater fields into the coastal ocean using the output of our hydrological models of watershed export (THEME 2A) and the ROMS modeling of nearshore flows. Our overall goal is to develop a parameterization for the time-dependent dilution field surrounding giant kelp forests as a function of hydrologic, current, surface wave and wind conditions following our previously developed methods for quantifying coastal connectivity, but for smaller spatial scales (Mitarai et

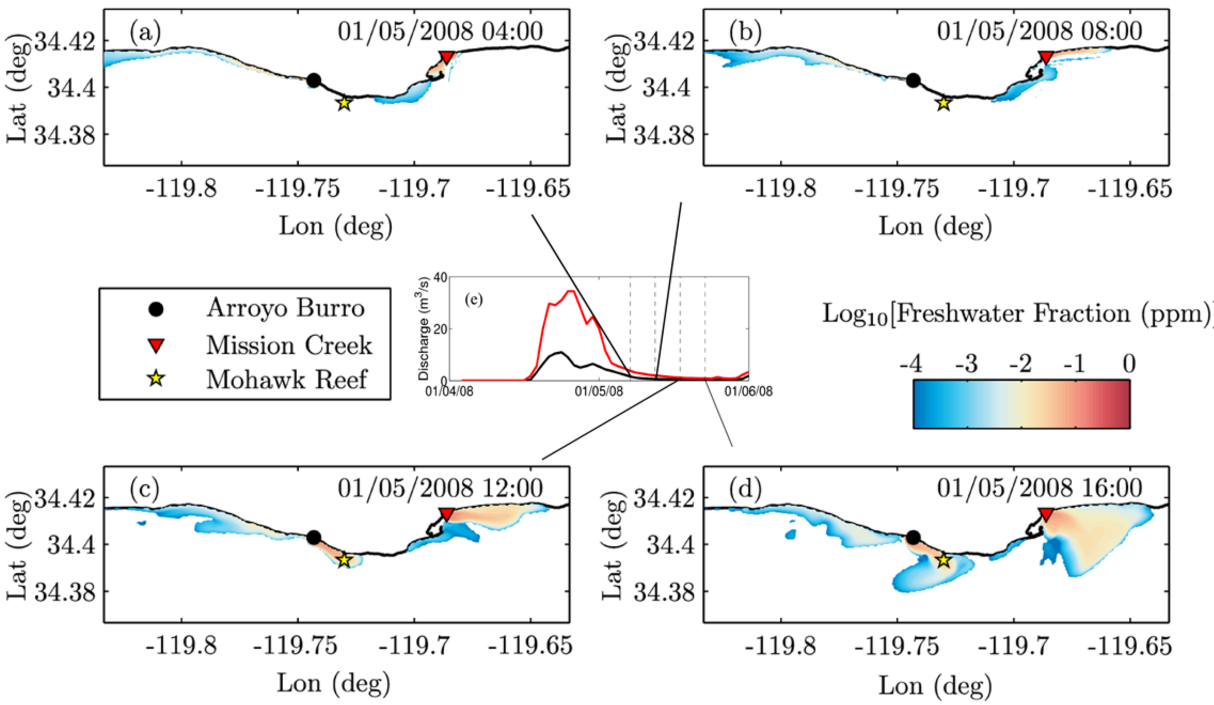

Figure 10. Spatio-temporal evolution of the freshwater runoff plumes from Arroyo Burro and Mission Creeks as determined bya ROMS simulation for January 5, 2008. Panels (a) through (d) show the evolution of the freshwater fraction at 1-hour intervals. The input hydrographs measured by SBC are shown in panel (e). The black circle, red triangle and yellow star note the locations of the outflows of Arroyo Burro Creek, Mission Creek, and the Mohawk kelp forest, respectively.

al. 2009). Accomplishing this goal will enable us to predict the fate of freshwater runoff and the organic and inorganic material that it carries.

The high resolution ROMS flow fields include realistic bathymetry, large-scale ocean forcings, spatial and temporally variable wind stress, tides, surface gravity waves and stream discharges (Dong and McWilliams 2007, Dong et al. 2009, Uchiyama et al. 2010, Buijsman et al. 2012). An example of the ROMS modeled freshwater discharges from Arroyo Burro and Mission Creeks shows the freshwater plume was restricted to the inner shelf and advected along shore from the two creek mouths (Figure 10). If this degree of retention is common, then it will greatly influence the amount of nutrients and organic matter delivered to kelp forests from runoff events. We will use the ROMS simulations to assess the flow structures that act as barriers to offshore transport of freshwater plume waters as a first step to developing a predictive understanding of plume water dilution and its influence on kelp forests.

We propose to validate and parameterize our models with data obtained from: (1) field deployments of a propelled autonomous underwater vehicle (AUV) that moves rapidly during short missions (~1 day), (2) a slower non-propelled oceanographic glider that uses changes in buoyancy for locomotion and is capable of missions up to a month in duration, (3) near-surface instrumented moorings that create time series of salinity and other properties in the upper 0.5 m of the ocean, and (4) water collections during storm events from small boats and piers. Measurements of salinity from the powered AUV, glider and near-surface moorings will be used to determine the freshwater fraction as functions of space and time. This will enable us to estimate dilution of stream water as a function of distance from the mouth of the stream, distance downstream and offshore, magnitude of discharge, buoyancy of the plume, and magnitude of currents and waves. The goal of these measurements is to characterize events observationally and to test the hypothesis generated from our preliminary modeling that alongshore flow structures confine the discharged freshwater to the inner shelf. The AUV will also measure horizontal currents with an acoustic Doppler current profiler (ADCP); moored ADCPs with surface wave measuring capabilities will also be deployed. Stream discharge levels and nutrient and particulate loading will be measured as part of our ongoing core monitoring (THEME 2A, Table 1). Small boat sampling will be done when conditions permit and from a pier near the mouth of Mission Creek and will include profiles of conductivity, temperature, optical particle scattering, and concentrations of chlorophyll a and nutrients.

THEME 3B. Nitrogen recycling and efflux from sediments

During SBC II we quantified the delivery of nitrate to giant kelp forests from freshwater runoff, internal tides and upwelling (McPhee-Shaw et al. 2007, **Fram et al. 2008**). We have shown that combining these estimates with models of nitrate uptake by giant kelp predicted nitrogen sufficiency for much of the year except during summer and autumn when measured nitrogen demand by giant kelp exceeded the calculated uptake of nitrate by two-fold (**Fram et al. 2008**). We hypothesize that recycled nitrogen supplies the missing nitrogen during summer and autumn. Monthly observations at our kelp forest sites show that ammonium concentrations exceed those of nitrate from June through December, and thus serve as an important source of nitrogen during this critical period (Figure 11a). We propose to investigate the importance of regenerated N to the nitrogen demand of giant kelp by measuring rates of nitrogen efflux from sediments and rates of N recycling by kelp forest consumers. These measurements will be

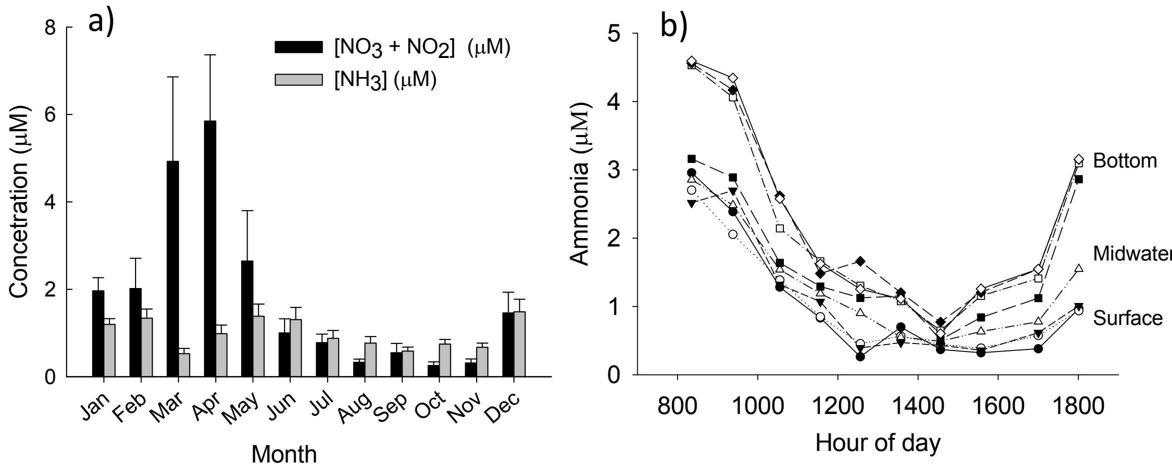

Figure 11. (a). Average monthly concentrations of nitrate + nitrite and ammonium at the three SBC kelp forest sites for 2001-2010. (b) Diel time course of ammonium concentrations at various depths throughout the 8 m water column immediately down coast of the Mohawk kelp forest.

coordinated with our proposed efforts to quantify the exchange of recycled nitrogen between beaches and the nearshore (THEME 2C and THEME 3A). We will incorporate the results of these studies into the kelp N uptake model of **Fram et al. (2008)** to test our hypothesis regarding the importance of recycled N to kelp nutrition. Collectively, these proposed studies will provide a more comprehensive understanding of the magnitude and importance of the various sources of regenerated N to giant kelp forests.

Our periodic measurements of fine-scale vertical variability in ammonium concentrations above soft sediments near reefs show a strong diel pattern that is inversely related to daylight and distance above the bottom and largely unrelated to tidal oscillations (Figure 11b). We hypothesize that organic matter decomposition within sediments supplies significant ammonium to kelp and other shallow water autotrophs and the concentration of ammonium in the water column is largely related to uptake by autotrophs during daylight hours. To test this hypothesis we propose to measure nitrogen efflux from sediments within and around kelp forests on a seasonal basis using benthic chambers equipped with stirring mechanisms, optode oxygen sensors (for measuring respiration) and MBARI ammonium sensors (Plant et al. 2009) set to sample every 15 min for 24 h. Paired opaque and transparent chambers will be deployed simultaneously during daylight hours to test our hypothesis that the diel pattern observed in ammonium concentration results from ammonium uptake by benthic autotrophs during daylight hours. Because ammonium levels are expected to show high frequency variations, sensors measuring tides, surface waves, currents and light, will be deployed near the chambers with MBARI ammonium sensors. Deployments will be for periods of several days to weeks on a seasonal basis to better understand the oceanographic processes controlling variability in ammonium concentrations within and adjacent to kelp forests.

Nitrogen processing by a diverse array of kelp forest consumers also is likely to contribute to the supply of recycled N via their excretion of ammonium and urea. Of special interest is ammonium excretion by epiphytes that live on macroalgae. One such epiphyte is the abundant colonial bryozoan *Membranipora* spp, which grows on giant kelp. It has been hypothesized to contribute significantly to giant kelp's nitrogen demand (Hepburn and Hurd 2005). We will examine the release of nitrogenous compounds from reef consumers by estimating the potential for nitrogen release using our long-term data of the biomass of over 150 species of kelp forest consumers together with their nitrogen excretion rates obtained from the literature for species where field measurements are impractical (such as highly mobile fish) and from laboratory measurements of key species more amenable to experimentation (e.g., sea urchins, sea stars, bryozoans). Recycling on the forest floor will also be evaluated directly using benthic chambers deployed over assemblages of sessile and weakly mobile consumers and over patches of detritus to directly measure nitrogen regeneration rates. In the water column we will focus on *Membranipora* spp. by measuring its excretion in the laboratory and by measuring the transfer of nitrogen from *Membranipora* to kelp in the field. The latter will be done by encasing kelp blades with *Membranipora* colonies in polypropylene bags, incubating them with ^{15}N-labelled phytoplankton for 24 h, and then analyzing the blades for ^{15}N content.

The contribution of recycled nitrogen supplied by the various processes (i.e., remineralization in beaches, efflux from subtidal sediments and excretion by reef consumers) to kelp nitrogen demand will be evaluated by determining the combined effect of these processes on ammonium concentrations in waters flowing through the forest, and then incorporating these concentrations into the kelp N uptake model of **Fram et al. (2008)**.

THEME 3C. Transport and fate of phytoplankton NPP

Results of our prior research showed persistent areas of high phytoplankton production in the Santa Barbara Channel **(Brzezinski and Washburn 2011**). The locations of some of these productivity hotspots (upstream, both offshore and down coast, of kelp forests along the mainland coast) make them potentially strong sources of phytoplankton for kelp forest communities. However, the seasonal nature of the cross-shelf processes that transport nutrients and phytoplankton to and from kelp forests (Goodman et al. in review, Halewood et al. in review) suggests that these subsidies occur mainly in spring and early summer. At other times of year kelp forest suspension feeders likely rely mainly on phytoplankton produced on the inner shelf (Page et al. 2008, Miller and Page unpublished data). The complexity of these nearshore transport processes are further demonstrated by our recently acquired oceanographic glider, which is being used to autonomously gather information on cross-shelf patterns in physical and bio-optical properties multiple times per day. Cross-shelf sections of temperature, chlorophyll fluorescence and light scattering (a proxy for suspended particle loads) off the Mohawk kelp forest reveal significant changes in the strength and location of the chlorophyll maximum and particle distributions over just a 10 hour period (Figure 12).

These results motivate new research concerning the mechanisms governing cross-shelf exchange and the degree of connectivity between plankton dynamics on the inner shelf with that occurring in offshore waters. We propose to address this topic by focusing on two primary mechanisms: (1) "reef-scale" dispersal of nearshore water masses and (2) high frequency (hours to weeks) cross-shelf exchanges.

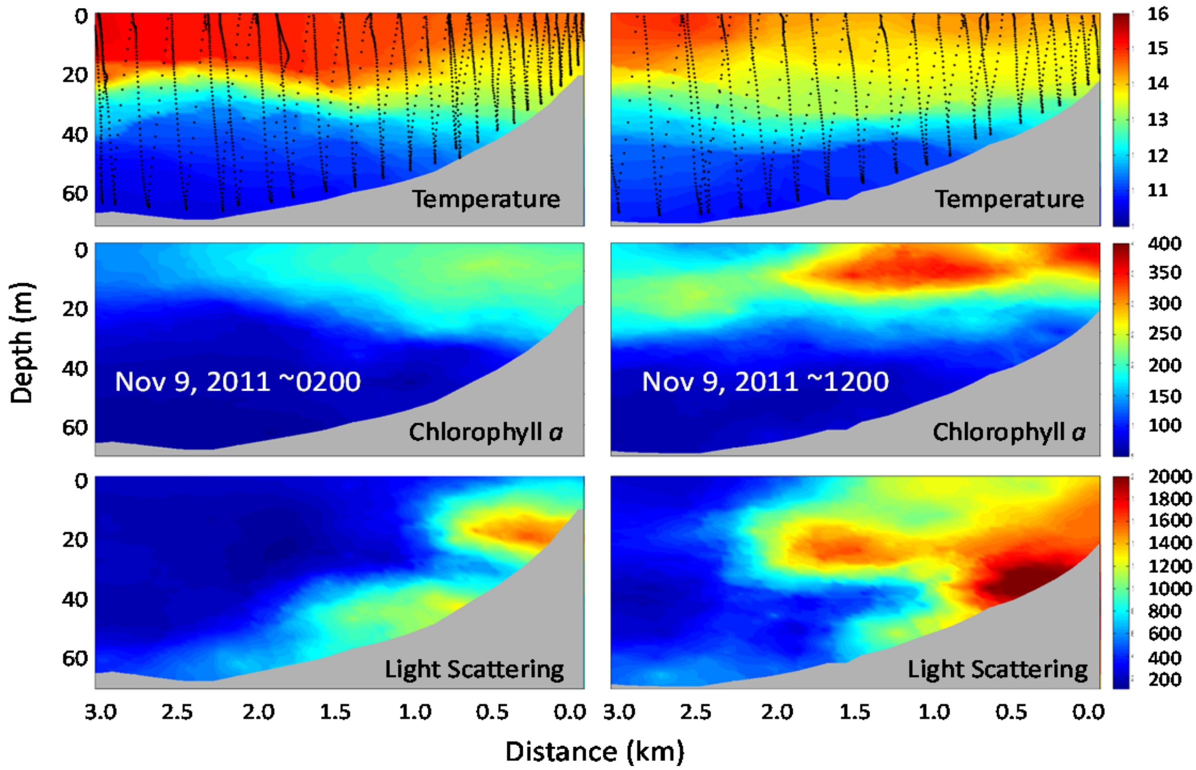

Figure 12. Observations obtained from a glider mission on November 9, 2011 showing strong vertical (depth) and cross-shelf gradients (distance) in temperature, chlorophyll *a* fluorescence and light scattering (optical backscatter at 660 nm) in the shallow waters offshore of the Mohawk kelp forest (0 distance = 0.5 km offshore of the kelp forest). The cross shelf patterns of these water properties changed greatly over just 10 hours. Light scattering is a useful proxy for resuspended sediments and suspended POM in the Santa Barbara Channel (Kostadinov et al. 2007, in press).

"Reef-scale" dispersal of nearshore water masses: Knowledge of cross-shelf and along-shore dispersal on submesoscales (length scales ranging from tens of m to ~10 km) is limited, yet it is transport of materials at these scales that is relevant to many marine ecological processes. Our preliminary modeling of water mass dispersal in a 250 m-resolution ROMS solution of the Santa Barbara coast shows that along-shore dispersal is much greater than cross-shelf dispersal in the nearshore compared to offshore where the two components of dispersal are very similar (Figure 13). We propose to further develop our ROMS modeling in THEME 3A to examine submesoscale dispersal rates on the shelf, targeting time periods of our SBC II cross-shelf exchange studies. The ROMS system will be refined to examine dispersal at ~50 m spatial resolution and will include the explicit modeling of surface gravity wave forcings (Uchimaya et al. 2010). This will allow modeled dispersal rates to be compared to our previously measured cross-shelf gradients in phytoplankton biomass and taxonomic composition on a seasonal basis. This time period included upwelling conditions when cross-shelf exchange appeared to be high and under stratified conditions when the inner shelf appeared more isolated (Halewood et al. in review). Our working hypothesis is that nearshore phytoplankton maxima observed under stratified conditions are maintained by higher phytoplankton growth rates and lower rates of cross-shelf dispersal for the inner shelf compared with offshore waters (Goodman et al. in review). This hypothesis will be tested by comparing the model output with field data and by ROMS simulation of phytoplankton blooms on the inner shelf using constraints for phytoplankton growth rate made during our previous cross-shelf studies (Goodman et al. in review). Where possible, rates of dispersal will be compared with existing surface drifter data from the SBC region (Ohlmann and Mitarai 2010).

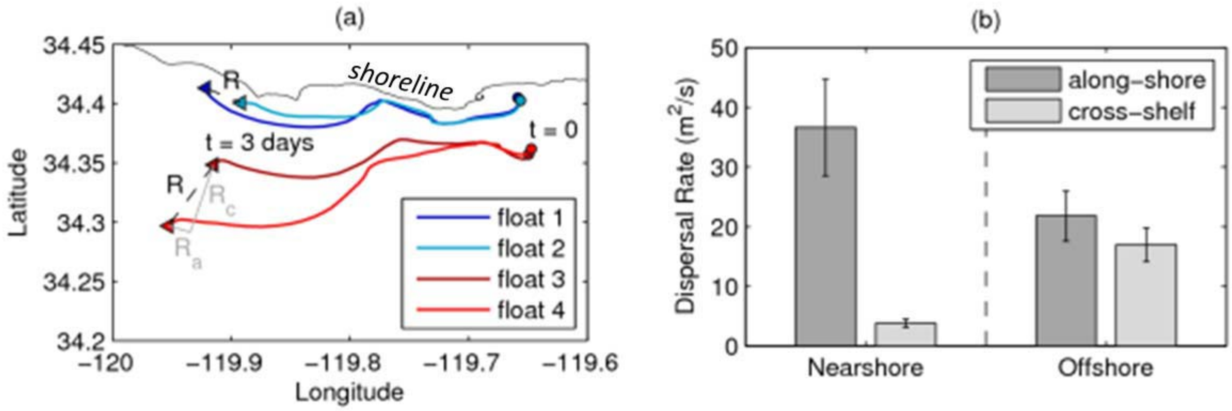

Figure 13. (a) Sample tracks of surface floats within a ROMS simulation with a horizontal resolution of 250m. The blue and red lines correspond to floats released near and far from the shore, respectively. The black dashed lines indicate the separation between the floats (R) 3 days after their release. The gray lines show the along-shore R_a and cross-shelf R_c, float separation components. (b) Results from ROMS simulation showing that dispersal rate nearshore in the along-shore direction is about 10 times larger than that in the cross-shelf direction. The dispersal rates were obtained from approximately $1x10^5$ floats released over a period spanning 3 months (winter 2007-2008)

High frequency cross-shelf exchanges: A host of processes control temporal changes in cross-shelf patterns in biological and physical oceanographic properties, including changes in wind-driven upwelling, continental shelf waves, submesoscale eddies, tides, and surface wave-current interactions (Figure 9). We will use both new and existing data to diagnose the importance of these mechanisms to cross-shelf exchanges. New data will be obtained from our autonomous glider, which measures temperature, salinity, dissolved oxygen, chlorophyll and colored dissolved organic matter (CDOM) fluorescence and particle backscatter at several wavelengths (Figure 12). The glider will sample repeatedly a cross-shelf section extending from the Mohawk kelp forest to ~5 km off shore. Each glider mission lasts nearly a month and four complete 5 km sections can be made each day resulting in >100 sections per mission. We will conduct four cross-shelf missions each year for the first two years of SBC III. During these missions, an instrumented mooring equipped with CTD and bio-optical parameters will be deployed inshore of the minimum depth that the glider can operate (~20 m).

Existing data that will be used in analyzing cross-shelf exchanges include data on current velocities and constituent distributions collected along the 20-40 m isobaths of the entire mainland coast of the Santa Barbara Channel during 16 UNOLS cruises during SBC I (2001-2006). These data consist of high frequency observations of temperature, salinity, optical transmission, chlorophyll fluorescence made from an undulating towed vehicle in conjunction with shipboard current measurements at a vertical resolution of ~1 m and a horizontal resolution of ~500 m. Using the cruise observations, we discovered that a significant fraction of phytoplankton NPP is subducted to depth along the shelf break, which represents a significant unrecognized component of organic matter export to depth (Dellaripa and Washburn unpublished data). In addition, hourly maps of surface velocity observations available from an array of HF radars will be used to quantify variations in cross-shelf exchange over the entire Santa Barbara Channel.

This rich assemblage of new and existing data sets will enable us to assess the roles of specific processes on cross-shelf patterns. For example, we recently used data from our instrumented moorings, HF radar and satellite imagery to diagnose the cross-shelf transport caused by wind-relaxation events (Washburn et al. 2011). We will build upon this work by combining our proposed glider observations and ROMS analyses to obtain a detailed understanding of how wind-relaxation events affect cross-shelf patterns of phytoplankton off

SBC kelp forests. Similar analyses will be performed for other processes (e.g., continental shelf waves, tidal frequency internal waves, submesoscale eddies).

CONCEPTUAL INTEGRATION AND SYNTHESIS

The research proposed for SBC III builds heavily upon our prior results and seeks to advance a general understanding of the roles of disturbance and climate variation in altering the structure and function of ecosystems that are highly connected via material exchange (Figure 4). We focus on giant kelp forests because knowledge of material exchange in this system requires integrated studies conducted in coastal watersheds, estuaries, beaches, and the inner and outer continental shelf. The relevance of our research, however, extends beyond coastal ecosystems of the Santa Barbara region as we address fundamental questions pertaining to biodiversity and ecosystem function, vulnerability and resilience of communities to climate change and fishing, metapopulation theory and dynamics, the roles of land use and fire on landscape change and watershed hydrology, and the physics of dispersal in the little studied coastal waters of the inner continental shelf.

One of the signal contributions of long-term ecological research is the ability to detect and understand ecosystem responses to decadal-scale changes in climate and natural and human-induced disturbances. We propose to meet this challenge by integrating our current 11-year LTER data sets with longer-term (~ 30 years) data obtained from government monitoring programs and satellite imagery. We also propose retrospective geological analyses to gain added insight into climate and disturbance effects on landscape change over much longer time periods (i.e., 100s to 1000s of years). Our syntheses of these integrated data are facilitated by the application of statistical and mechanistic models that we developed from our LTER data sets, which enable us to predict important, but difficult to measure response variables (e.g., organismal biomass, NPP, stream export) from data of variables that are routinely measured (e.g., species abundance, precipitation, land cover type). Our proposed efforts in this area will greatly expand the temporal and spatial inference of our analyses and lead to a more comprehensive synthesis of the response of coastal ecosystems to variation in climate and disturbance.

Notably, the high disturbance regime, rapid recovery times, complex food web dynamics, high levels of productivity, and dramatic ecological responses to prominent climatic signals (e.g., ENSO, PDO, and NPGO) of our study systems bring a valuable perspective to LTER Network level synthesis. Our activity in these network-level activities has increased considerably with the increasing temporal and spatial inference of our data (see Section 4 Midterm Evaluation). We fully anticipate that the research proposed in SBC III will create many new opportunities for cross-site synthesis with the LTER Network and elsewhere.

SECTION 3 – OUTREACH AND EDUCATION

Santa Barbara Coastal LTER Education and Outreach includes programs that range from K-12 education, to teacher professional development, undergraduate and graduate student training, and stakeholder engagement. SBC students, postdoctoral scientists, and investigators are actively engaged in all facets of our education and outreach efforts. Below we describe the primary activities of each area and plans for future development and implementation.

SCHOOLYARD LTER

The Santa Barbara Coastal Schoolyard LTER (SLTER) focuses on two foundational programmatic elements: (1) environmental education programs for middle school students and (2) research and professional development for environmental science literacy. Our SLTER is led by a PhD scientist with expertise in science education (Whitmer), and an education coordinator (Simon), with substantial involvement of SBC students and investigators.

Environmental Education: Our on-going summer environmental education program utilizes SBC research themes of marine science and watershed ecology to engage students in learning about the coastal environment. Our principal program is offered in collaboration with the American Association of University Women's summer *Tech Trek* program. *Tech Trek* is a math/science residential program designed to develop interest, excitement and self-confidence in young women who will be entering the eighth grade. The program brings 150 middle school girls to UCSB each summer to work with our education coordinator and undergraduate docents. Our SLTER program has developed a series of lessons on how press and pulse disturbances (fire, El Niño, climate change, etc.) impact watershed and ocean systems and their influence on kelp forest dynamics. Our program has become the model for other outreach programs working with *Tech Trek* and our association with them provides us with an opportunity to expand our reach.

Working with *Tech Trek* over the last several years has allowed us to develop and assess research-based curricular materials on a similar population of students. These assessments have provided rich information on how to appropriately and effectively incorporate SBC research and data in middle school educational materials. In the coming years we will continue our *Tech Trek* work as well as develop additional educational materials and programming that will be implemented in our educational marine aquarium facility, The REEF. Our materials will be aligned with California state standards for middle school science in addition to the guidelines for California's Environmental Education initiative.

Pathways to Environmental Literacy: Along with the BES, KBS, and SGS LTER Schoolyard programs, the SBC Schoolyard program is a core partner in an NSF-funded Math Science Partnership (MSP) project that focuses on environmental literacy in K-12 education. Through this partnership we have worked with middle school teachers in professional development workshops and in their classrooms to improve student understanding of key environmental concepts, including the water cycle, carbon cycle, and biodiversity. We use SBC research and field sites as the basis of our activities. In particular, we have partnered with an underserved, low-achieving school, La Cumbre Junior High School, and work with all three of their science teachers (life and physical sciences) and all of their 7^{th} and 8^{th} grade students. We also work with an additional ~20 local middle and high school teachers from three school districts. Teacher professional development focuses on lesson plan development, in-class implementation of these lesson plans, and research on student learning.

In the remaining 3 years of our MSP project, we will continue our work with teachers and students and focus on data analysis of the hundreds of student assessments we have conducted in Santa Barbara schools. We will further develop our professional development program, which currently serves as their primary program at La Cumbre JHS. We will focus on work with additional school administrators to institutionalize SBC's SLTER program in their schools and serve as partners in their teacher professional development programs. These efforts will provide the foundation for long-term relationships between our MSP school partners and SBC.

UNDERGRADUATE EDUCATION

SBC's undergraduate education program includes both research and science education experiences through mentoring by graduate students, post-docs, research staff and investigators. Undergraduate students who participate in our interdisciplinary research program are exposed to a variety of hands-on research in kelp forest community ecology, coastal oceanography and watershed science as well as training in data management and processing. Students from this pool and elsewhere are selected to participate in our Research Experience for Undergraduates (REU) program and in several other mentorship programs sponsored by the University of California. REU students work closely with SBC researchers on a wide range of topics and most choose to pursue an advanced degree following their undergraduate education.

Our undergraduate students also engage in our K-12 education programs through docent and internship positions. Our training program provides a foundation of pedagogical and content knowledge, which allows our docents to effectively communicate and teach marine science generally and SBC research in particular. Furthermore, a number of graduates have gone on to careers in both formal and informal science education. Future efforts in education program will focus on enhancing student training programs, particularly in the area of metacognition. Students will engage in reflective exercises that directly connect their experience in communicating science to K-12 students to evaluating their own learning styles and depth of content knowledge.

POST GRADUATE EDUCATION

SBC graduate student and postdoctoral training is coordinated with several graduate programs on the UCSB campus most notably, the Interdepartmental Graduate Program in Marine Science, the Department of Ecology, Evolution and Marine Biology, Department of Geography and the Bren School of Environmental Science and Management. SBC works with these programs to promote opportunities for interdisciplinary graduate research that examine how coastal ecosystems change in response to natural and human-induced alterations in the environment. Students and postdoctoral scientists work on topics in terrestrial, aquatic, and marine environments with interests ranging across ecology, physiology, geology, hydrology, oceanography, 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 postdoctoral scientists that fosters a respect and appreciation for other disciplines. We recently instituted a 10 week seminar course for graduate and advanced undergraduate students that focuses on major research themes of the SBC LTER. The course includes student led presentations and discussions and is widely attended by all project participants. Our graduate students meet annually with graduate students from CCE and MCR to participate in a student organized California LTER Graduate Student Symposium that is designed to allow students to share their work with students from other LTER sites. Additionally, we make funds available to all SBC graduate students to attend the tri-annual LTER Network All Scientists Meetings.

APPLICATION TO POLICY AND MANAGEMENT

The research proposed for SBC III has direct applications to the policy and management of several topical issues for coastal regions. SBC investigators are working with the cities of Santa Barbara, Goleta and Carpinteria to secure funding to develop a vulnerability assessment of the region's coastal ecosystems to climate change for use in local planning. Our proposed research on marine protected areas will provide a long-term perspective of the effects of fishing on kelp forest ecosystems and will be useful for informing future management decisions. SBC research on sandy beaches continues to play an informative role in ongoing public debates among different user groups over coastal management practices such as coastal armoring and beach grooming and filling. Results from SBC research on kelp forests have been incorporated into the monitoring of a state mandated mitigation project aimed at compensating for the loss of marine resources caused by the operation of a coastal nuclear power plant (Reed et al. 2011b).

SECTION 4 –MID-TERM EVALUATION

The midterm review of SBC II was generally very favorable and the panel identified no issues that required mid-cycle changes. The panel made several suggestions for us to consider in the proposal for SBC III. Below we briefly describe how we addressed these suggestions.

SITE-BASED SCIENCE:

- A long-term experiment assessing the ecosystem effects of fishing disturbance was included to take advantage of the recently implemented marine reserves along the mainland coast.
- Our proposed studies of the dispersal of buoyant plumes and the fate of kelp NPP are in line with suggestions made by the panel to follow watershed inputs and kelp forest exports.
- The research themes of SBC III were revised as suggested to better reflect the major foci of SBC science.
- We proposed a variety of modeling techniques that aim to integrate various components of our research and extend the spatial scales of our analyses as suggested.
- Research employing newly developed Landsat data sets, analyses of cosmogenic nuclide concentrations and geological history of sediment deposits, and cross-site ocean pH sensor arrays is proposed to broaden the spatial and temporal scales of our research and to allow our results to be better placed in the context of climate change. As suggested we added GIS and socio-geographic expertise (Roberts, Bookhagen, and Simms) to examine climate related changes in soil erosion, sediment deposition and land cover and are working with climatologists from Scripps Institution of Oceanography (D. Cayan, S. Iacobellis) and local city officials to obtain additional funding to develop scenarios of climate change vulnerability of coastal ecosystems in the Santa Barbara region for use by policy makers.

NETWORK PARTICIPATION: As suggested we have sought additional opportunities for cross-site synthesis. Ongoing cross-site studies that we initiated since our midterm review include: an oceanographic study of island circulation and wakes with CCE and MCR; the processing and fate of subtidal macrophyte subsidies to intertidal ecosystems with VCR; spatial and temporal patterns of ocean pH with MCR, CCE and PAL; processes and mechanisms promoting community phase shifts with CCE, JRN, HFR, and PAL; a cross-site comparison of microbial diversity (MIRADA), regional drivers of kelp NPP with PISCO scientists from UC Santa Cruz; participation in a cross-site working group on Long-Term Experiments in the LTER Network with 9 other sites; a cross-site partnership program of teacher professional development in environmental literacy with SGS, KBS, BES, and LNO, and the adaptation of a central relational metadata model with GCE, MCR and CWT that supports current LTER NIS protocols.

INFORMATION MANAGEMENT: We incorporated all the panel's suggestions for IM except the suggestion to provide our data in GIS formats in addition to our current ASCII formats. This suggestion is not practiced by most sites in the LTER and adopting it would require substantial effort and resources. NSF stated that they had no strong feeling on this suggestion so we chose not to incorporate it.

SITE MANAGEMENT: We reconstituted our Executive Committee as suggested (Supplement 3 - Site Management Plan).

EDUCATION AND OUTREACH: We instituted an annual graduate seminar as a means of better introducing students to the goals and research findings of SBC.

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FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages if necessary.

Laboratory:

SBC Principal and Associate Investigators have laboratory space in the Marine Science Institute (MSI), Department of Ecology, Evolution and Marine Biology (DEEMB), Department of Geography, Department of Geology, Earth Resources Institute, Environmental Studies Program and the Donald Bren School of Environmental Science and Management at UCSB that is sufficient for the project's needs. In addition, over 900 ft^2 of laboratory space in UCSB's Marine Science Building has been assigned specifically for SBC LTER use. We also have access to common laboratory space in the Marine Science Building, Bren Hall and in DEEMB's marine biotechnology building, including environmentally controlled temperature rooms and rooms supplied with running seawater. MSI's Analytical Laboratory is a professionally managed shared-use instrumentation and chemical analysis facility that is well equipped to perform nearly all of the chemical analyses anticipated for this project. Major capabilities of the Analytical Lab include elemental analysis of inorganic and organic substances, stable isotope ratio determination of biological materials, and automated determination of nutrients in natural waters.

Clinical: not required for this project

Animal: not required for this project

Computer:

Each of the investigators in this project maintains computing capabilities commensurate with their specific research activities. Data management for the project has the advantage of utilizing the computing capabilities of the Marine Science Institute (MSI). MSI has a 1000Mb/s connection to the UCSB campus backbone, which provides shared access to a 622Mb/s CALREN-2 connection, which in turn provides access to the Internet. MSI supports the research servers. The main data server providing network file sharing (Samba and NFS) is a running RedHat Enterprise Linux 5 (64-bit). The data server also runs SVN for revision control systems, SAS, Matlab, GSLIB and PERL for scientific applications. Currently we have 11.5 TB of storage (expandable) available on that system. The second server is running RedHat Enterprise Linux 5 (64-bit), which runs the Apache web server, and the Tomcat java servlet engine. A third server running RedHat Enterprise Linux 4 (64-bit) is the primary database server, running PostgreSQL, MySQL and the personnel database (LDAP). The Server room is connected to E-Power, and redundant power is provided by an APC 6000 UPS battery backup. Distributed server backups (via Amanda) are coordinated with MSI.

The Earth Research Institute (ERI) provides computational support for the processing of satellite imagery and ROMS ocean circulation modeling. It consists of a network of: more than 50 UNIX servers, workstations, and clusters. Two Linux clusters ("Gill" and "Riley"), are available for SBC research. Gill is used for conducting ROMS simulations and offline particle tracking and has 16 Quad-Core 2.6 GHz AMD CPU's with 64 Gb of RAM and 7.3 Tb of disk. Riley is used for high performance MATLAB post-processing and analysis of satellite imagery. It has 16 Quad-Core 2 GHz AMD 8350 CPU's, with 16 GB of RAM and 5.5 TB of disk. The size of the ROMS outputs are very large (often 2-3 TB per three month simulation) and we recently received funds as part of an equipment supplement from NSF to acquire a 42 TB data server (with backup) for SBC ROMS output and satellite data sets. This data server is being procured now and will be integrated with the Linux clusters at ERI. We also have access to a 1008 CPU MPI cluster for campus researchers which was recently funded on a NSF Major Research Infrastructure grant (http://csc.cnsi.ucsb.edu/clusters/knot).).

Office:

All SBC Principal and Associate Investigators have adequate office space to meet their needs and those of the postdocs and graduate students associated with this project. All offices are equipped with phone and internet services.

Other:

Special facilities are not required at our field sites, which are all located close to campus.

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

Most chemical analyses will be done using instrumentation in MSI's Analytical Laboratory. Major equipment in the MSI Analytical Lab include: two atomic absorption spectrophotometers (AAS) with auto samplers, one instrument equipped for flame atomization, and the other a dedicated furnace system with Zeeman background correction; a microprocessor-controlled gas chromatograph (GC) with various detectors, including flame ionization and photo-ionization; two automated organic elemental analyzers for CHN analyses, an isotope ratio mass spectrometer interfaced with a CHN sample introduction system, and an automated 5-channel wet-chemical analyzer (FIA) for nutrients.

Equipment purchased with previous LTER funding include two WS Oceans *in situ* nitrate analyzers, an ISUS V3 chemical free nitrate analyzer, 6 Wetlabs Eco-DFLSB fluorometers, 1 Wetlabs Eco-triplet rhodomine, chlorophyll and CDOM fluorometer, 6 Wetlabs ECO-VSFSB volume scattering function meters and 6 Seabird Electronics SBE37SM CTD's, 40 Brancker TR-1050 self-contained temperature loggers, 6 Optode self-contained oxygen sensors, 5 Honeywell Durafet® pH sensors with temperature probes, 1 high Resolution TCO2/ pCO2 system, 8 ISCO automated stream samplers, 1 Teledyne Webb Slocum Autonomous Glider system, 5 acoustic Doppler current profilers, one 22 ft. research boat and trailer equipped for SCUBA and water sampling operations, one mini-rosette with CTD and winch for nearshore oceanographic sampling, one Ford Expedition equipped for towing the 22 ft. research boat, 1 Toyota pick-up truck for use in watershed sampling.

The laboratories of several investigators are equipped with additional instrumentation that will be used to do the proposed work including: a Turner 10AU fluorometer for phytoplankton chlorophyll determination (Brzezinski), a Lachat Autoanalyzer, C/N analyzer, gas chromatograph, and an infrared gas analyzer to be used in nutrient analyses and soil chemistry (Schimel). Additional oceanographic instrumentation available to this project include two acoustic Doppler velocitometers, 21 acoustic Doppler current profilers (Washburn and MacIntyre) and 12 high-frequency radar units (Coastal Ocean Dynamics Applications Radars, CODAR) for measuring surface currents (Washburn).

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

UCSB has the facilities and trained technical staff typical of large research universities. Resources that will be of most value to this project include: machine, electronic, and carpentry shops for constructing apparati for the laboratory and field, a large capacity seawater system, a fleet of small vessels that are maintained by a certified boat mechanic, and a research diving program that includes ~ 130 scuba tanks, and a compressor and technician to fill them. Use of university equipment and consultant and technician services are available to us, generally on a recharge basis.

UCSB is highly supportive of the SBC LTER and will provide additional resources (e.g., research staff support, analytical costs, transportation services) when available. This will be done on an as needed basis to ensure that the project meets its research objectives.

SUPPLEMENT 1. SBC ELECTRONICALLY ACCESSIBLE DATASETS

Current inventory of variables measured, spatial and temporal extent, dataset identifiers, and usage for: (a) SBC long-term time-series data, (b) SBC experiments and shorter-term measurement-intensive process studies, and (c) exogenous reference data assembled or used by SBC. Dataset identifiers are prefixed with "knb-lter-sbc" (example in each row), and can be reached from either the SBC data catalog (http://sbc.lternet.edu/data) or the LTER Network catalog (http://metacat.lternet.edu). "Usage" reflects data requests or downloads from outside investigators or others not associated with SBC. The total number of downloads is given, followed by subtotals in parentheses for Academic Research, Education (all levels), and other (including unknown). All data are Type I unless indicated otherwise.

a) SBC long-term time-series data.

Habitat	*Variables measured*	*Spatial extent*	*Temporal Coverage*	*Sampling frequency*	*Dataset IDs*	*Usage Jun 2006-Sep 2011*
Land	Precipitation	12 gauges	2001-ongoing	5 min	knb-lter-sbc.5001 - 5012	32 (16, 1, 15)
	Stream discharge	16 gauges	2001-ongoing	5 min	3001-3016	77 (41, 12, 24)
	Stream chemistry (nitrate, ammonium, phosphate, total dissolved N & P, total particulate N & P, particulate organic C, total suspended sediments, conductivity)	13 sites	2000-ongoing	Weekly, biweekly, or as required by events	6	59 (43, 2, 14)
Beach	Macroalgal wrack biomass & species composition	5 beaches	2008-ongoing	Monthly	knb-lter-sbc.40	0
	Abundance of stranded kelp (*M. pyrifera*) plants	5 beaches	2009-ongoing	Monthly	51	0
	Abundance of birds	5 beaches	2008-ongoing	Monthly	51	0
Kelp forest	Population dynamics of > 200 species of kelp forest algae, invertebrates, and fish	11 reefs	2000-ongoing	Annual	knb-lter-sbc.15, 17, 18, 19, 43	337 (243, 21, 73)

Habitat	*Variables measured*	*Spatial extent*	*Temporal Coverage*	*Sampling frequency*	*Dataset IDs*	*Usage Jun 2006-Sep 2011*
	Bottom water temperature	11 reefs	2002-ongoing	15 min	knb-lter-sbc.13	38 (17, 1, 20)
	Foraging habitat, benthos, prey biomass, surfperch density and size structure	Santa Cruz Is, 11 reefs	1982-ongoing	Annual	38, 39, 46, 47, 48	0 (acquired 2010)
	Landsat imagery of giant kelp canopy biomass	So. Calif Bight	1984-ongoing	Monthly – bimonthly	54	0 (acquired 2011)
	Giant kelp biomass, growth, loss, NPP and stoichiometry	3 reefs	2002-ongoing	Monthly	21, 24	61 (24, 1, 36)
	Population dynamics of > 200 species of kelp forest algae, invertebrates, fish, algal allometrics, and detritus biomass for cleared and control plots	4 reefs	2008-ongoing	Monthly	26, 28, 29, 30, 34, 44, 25, 27, 49, 50	68 (54, 7, 7)
	Irradiance at the surface and seafloor for cleared and control plots	4 reefs	2008-ongoing	Daily (aggregated)	36	0
	Kelp biomass and harvest from ISP Alginates	Monterey - Baja CA	1957 – 2007	Approx. monthly	14	63 (36, 6, 21)
Inshore Ocean	Current velocity, water conductivity & temperature (moorings)	5 sites	2001-ongoing	Every few minutes	knb-lter-sbc.2001-2005, 2007	71 (34, 5, 32)
	Profiles of conductivity, temperature, dissolved nutrients (C, N, P, Si), particulate organic C and N, chlorophyll a	5 sites	2001-ongoing	Monthly	10	66 (23, 3, 40)

Habitat	*Variables measured*	*Spatial extent*	*Temporal Coverage*	*Sampling frequency*	*Dataset IDs*	*Usage Jun 2006-Sep 2011*
	Invertebrate larval settlement	6 sites	1990-ongoing	Biweekly	knb-lter-sbc.52	0 (acquired 2011)

b) Data from experiments and short-term, measurement-intensive process studies

Habitat	*Variables measured*	*Spatial extent*	*Temporal Coverage*	*Sampling frequency*	*Dataset ID*	*Usage Jun 2006-Sep 2011*
All	Carbon and nitrogen stable isotopes (^{13}C, ^{15}N) in POM, kelp, consumers, and kelp-derived detritus	8 sites	2000-2005	Varied	knb-lter-sbc.12	19 (18, 1, 0)
Beach	Intertidal kelp wrack biomass and pore water nutrients (N, P)	10 beaches	2003	Once	knb-lter-sbc.23	0
	Kelp wrack biomass and cover	1 beach	2005-2006	Semi-monthly	22	31 (7, 2, 22)
Kelp forest	Primary production of understory algae (turf and foliose) and phytoplankton	1 reef	2006, 2007-2008	Monthly	knb-lter-sbc.37, 55	0
	Photosynthesis vs. Irradiance (P vs. E) for macroalgae	NA	NA	Once	§57	0
	Taxon-specific primary production for cleared and control plots	4 reefs	2008-2010	Seasonal	§58	0
	Microsatellite loci with GenBank IDs for *M. pyrifera*	1 reef	2006	Once	53	0
	Kelp forest food web	NA	NA	NA	56	0
	Species richness and urchin grazing	1 reef	2009	Twice	§59	0

Habitat	*Variables measured*	*Spatial extent*	*Temporal Coverage*	*Sampling frequency*	*Dataset ID*	*Usage Jun 2006-Sep 2011*
Inshore Ocean	Dissolved and particulate organic C and N, dissolved nutrients (N, P, Si), chlorophyll a, bacterial abundance and productivity and phytoplankton abundance	5-site transect at one reef	2008-2009	Monthly	§knb-lter-sbc.45	1 (1, 0, 0)
Offshore Ocean	Primary production, profiled conductivity, temperature, inorganic nutrients (C, N, P, Si), pigments, particulate organic C and N, ^{15}N and ^{13}C isotopes. Occasional: biogenic & lithogenic silica, optics, dissolved organic C	32 sites, Santa Barbara Channel	2001-2006	3 cruises per year	knb-lter-sbc.1001 -1016	65 (38, 1, 26)
	Continuous current profiles, surface water temperature, salinity, fluorometry, air temperature, barometric pressure, solar radiation, PAR	Santa Barbara Channel	2001-2006	3 cruises per year	1101-1116	6 (3, 0, 3)
	Conductivity, temperature, depth in cross-channel transects	8 transects, Santa Barbara Channel	2001-2006	3 cruises per year	1201-1216	6 (3, 0, 3)

§ Type II data

c) Exogenous, publically available reference data assembled or used by SBC (Type 0).

Habitat	*Variables measured*	*Spatial extent*	*Temporal coverage*	*Sampling Frequency*	*Dataset ID*	*Usage Jun 2006-Sep 2011*
Land	Daily precipitation at UCSB (Santa Barbara County)	1 gauge	1951-ongoing	Daily	knb-lter-sbc.33	5 (2, 0, 3)

Habitat	*Variables measured*	*Spatial extent*	*Temporal coverage*	*Sampling Frequency*	*Dataset ID*	*Usage Jun 2006-Sep 2011*
	High-frequency precipitation (Santa Barbara County)	16 gauges	Varies (ongoing)	5 minutes	knb-lter-sbc.5001-5016	6 (5, 0, 1)
	Daily precipitation (various terminated time series)	28 gauges	Varies	Varies	3	30 (21, 0, 9)
Inshore Ocean	Manually collected sea surface temperature (SIO, UCSD)	1 site	1955-ongoing	Daily	knb-lter-sbc.32	31 (12, 0, 19)
	Modeled significant wave height and period (SIO, CDIP)	9 reefs	2001-ongoing	Hourly	35	0
Offshore Ocean	Sea surface temperature, chlorophyll a, sediments from satellite remote sensing (ERI, UCSB)	S. Calif Bight	1997-ongoing	Daily	Not cataloged by SBC LTER	N.A.
	Surface currents from high frequency radar (ERI, UCSB)	S. Calif Bight	1999-ongoing	Hourly	Not cataloged by SBC LTER	N.A.

SUPPLEMENT 2 - INFORMATION MANAGEMENT PLAN

SBC Information Management System

The principal mission of SBC's Information Management System (SBC IMS) is to ensure the availability of SBC data to a broad research community. Our primary objective is to facilitate diverse research and outreach goals by focusing on ease of data access, organization, integrity, and long-term preservation. Since its inception, SBC has chosen cross-platform Internet standards designed for the LTER Network exchange specification to simplify our data presentation and delivery and to increase awareness of LTER data-sharing practices. The SBC IMS and website (http://sbc.lternet.edu) currently meet or exceed all standards listed in the LTER Network's Review Criteria for LTER Information Management Systems and Guidelines for LTER Web Site Design and Content. We anticipate the IM standards of the LTER Network will continue to evolve with emerging technologies and information needs. We have been very active in the planning and development of the LTER Network Information System (see ***Related projects,*** below) and we will maintain our leadership role in this area to ensure that the SBC IMS is well positioned to meet the future expectations for LTER IM. To prepare for this we will continue to streamline the SBC IMS and converge on standard practices during SBC III to facilitate and improve data integration with other sites in the LTER Network.

Scope of data and metadata

The SBC IMS manages diverse data from the many scientific disciplines represented in the major ecosystems of our coastal study domain: watersheds and streams, beaches, subtidal reefs, and oceans (Supplement 1). We currently incorporate data produced from several distinct processing and software environments (e.g., SAS, Matlab, MS-Excel), and anticipate additional types of data to be added in SBC III (e.g., raster imagery). The SBC IMS delineates products from all SBC's research approaches (e.g., long-term time-series, experiments, short-term measurement-intensive process studies, and synthesis/modeling), as well as integrates legacy studies and exogenous (non-SBC sources) reference data.

The top priority of the SBC IMS is to provide online access to all of SBC's core data and accompanying metadata through the SBC and LTER Network data catalogs. All SBC metadata are presented in Ecological Metadata Language (EML) and conform to all LTER best practices for content such as keywords, personnel, geo-location, methods and data accessibility. The volume and diversity of our data require a centralized metadata system for multiple uses including EML dataset generation. For this reason we recently teamed with 3 LTER sites (MCR, CWT and GCE) to increase our efficiency and ability to adapt to future LTER IM standards by adopting GCE's database model, Metabase. Dynamically generated datasets from Metabase are more efficient to maintain and more adaptable to the increasing expectations for LTER data than semi-manual dataset construction. Metabase is capable of producing fully described datasets for automated metadata-driven use.

Policies

SBC has adopted the LTER General Use Agreement and the Network's "Type I-II" designations. Nearly all SBC data are Type I (i.e., publicly available within 1-2 years of collection or laboratory analysis) although some ongoing electronic data are available much sooner. Our policy is to describe Type II data (e.g., from a student thesis) in our public catalog, but to set distribution information for the tables to "offline", and instruct interested parties to contact us for access to the data. To ensure that researchers contribute their data to the SBC IMS, all participation in SBC funded research is contingent upon data being published in a timely manner. We employ a "Type 0 (zero)" designation for data acquired from outside parties that are typically already public (e.g., USGS stream flow), and occasionally republished. A description of our data policy and the terms of SBC's data use are available on the SBC website at http://sbc.lternet.edu/data/data_agreement.html.

Operation, infrastructure and resources

The major features of the SBC IMS are summarized in Table S2.1. SBC IMS leverages the Marine Science Institute and the UC Santa Barbara campus network infrastructure for its web, database and file servers. Off-site backups (stored in another building on the UCSB campus) provide for disaster recovery, and individual files can be restored as needed from daily on-site backups. In addition, the entire public data catalog inventory is cached as a DVD archive. The common data arrangements have been stable for many years, which enable users to remain familiar with the structure; the file server organization is publicized to assist new users. All research groups have dedicated directories for "working" and "final" data products that are accessible for shared internal use. All SBC personnel may view any data file, but write-access is limited to those responsible for data collection and maintenance. With this system, data are available to all SBC members immediately.

Table S2.1. Major features of the SBC Information Management System (SBC IMS)

Type	Feature	Specification
Website, searchable catalogs and/or directories	*http://sbc.lternet.edu *Bibliography *Personnel directory *#Data *Signature datasets §Research projects §Sampling sites (in progress)	XHTML, Perl, PHP, XML, XSLT, JavaScript, CSS2 EML LDAP EML EML LTER-project XML SBC-places XML, KML
Datasets	146 datasets (189 data tables) available in the SBC and LTER Network Catalogs	EML
Database	§SBC Metabase, Metadata exchange	GCE Metabase2, PostgreSQL EML
Servers & user accounts	Web, database and file systems, backup 159 user accounts	LINUX, SAN, ext4, rsync LDAP
Code Repository	Versioning of code, data models, website components and system documentation	SVN, SchemaSpy, DokuWiki

Notes: *feature required by all LTER sites, #searchable by creator, LTER core area, site keywords, §further described in text

SBC IMS is co-located with the IM system of the Moorea Coral Reef LTER (http://MCR.lternet.edu), and SBC's IM staff actively interacts with members of the NCEAS Ecoinformatics Program (http://nceas.ucsb.edu/ecoinfo). M. O'Brien has served as SBC's information manager since 2004 at 0.75-0.875 FTE; her remaining time is funded from other sources to work on a variety of IM projects (see ***Related projects***, below). She is responsible for directing scientists and technical staff in the planning and production of all SBC LTER datasets for publication. As a close collaborator, M. Gastil-Buhl (MCR information manager) is well acquainted with the SBC IMS, and many IM tools are shared by the two sites, which provides reinforcement during absences. SBC and MCR have jointly planned all new IM projects since 2009. During 2011, NSF supplemental funds to the two sites were combined to support a shared assistant during the porting and adoption phase of GCE Metabase.

SBC's IMS is documented at several levels: (1) as a general Information Management Plan which is updated annually, (2) as an IM Guide (Wiki), whose intended audience is the IM staff and assistants, and (3) as schematics, descriptions and other supporting documentation of individual system components as reference material for future IM staff. The IM Plan is available through SBC's website (http://sbc.lternet.edu/information_management); the IM Guide and project documentation are intended for internal use and a guest login is available for reviewers of this proposal.

Integration of IM with site research

Communication between SBC scientists and Information Management is fostered by the SBC IMS Advisory Committee (IMSAC), which includes co-PI Melack (chair), IM O'Brien and two rotating Investigators from different research fields. The IMSAC establishes priorities for SBC's IM activities and increases the scope of researcher involvement in the SBC IMS. The IMSAC reports to the Executive Committee (see Supplement 3). Information Manager O'Brien works closely with researchers to design data products for the SBC Data Catalog. She routinely meets with investigators and research staff to give guidance on standards for the content, format and completeness of data and metadata.

SBC IMS has well-developed processes for maintaining different kinds of datasets. Long-term datasets in particular require considerable planning and discussion. SBC's usual practice for these data is to compile them into a single multi-year product, which greatly enhances the convenience for data users interested in assessing long-term patterns. Changes in methodology are unavoidable in the case of some long-term time series. Any such changes to methods are promptly recorded in protocol documents and dataset metadata, and formats standardized.

SBC Information Management System features

The variety of SBC's data and processing pathways requires us to employ several strategies for building data packages (i.e., data plus metadata) for online access. Data packages with repetitive formats are created with scripts that modify EML templates. Our practice is to create scripts in the language used by the data owners, which accommodates the different skill sets of our scientists and allows dataset publication to become the last step in data processing. For example, processing of data from sensors and oceanographic cruises (which comprise about 50% of the total datasets by number) is done by research staff using Matlab. The publication of these data is accomplished via Matlab scripts written by O'Brien that populate EML templates. Other long-term time-series datasets (e.g., kelp forest community data) require individual handling for updates. The data are managed by research staff in SAS, while the EML metadata are currently updated manually by the IM staff (O'Brien and student assistants). Our recent transition to Metabase will facilitate handling such unique datasets in an automated manner.

Data quality control has evolved in the laboratories of individual research groups with oversight by the information manager, and flag-fields are accommodated in metadata. For example, quality control measures with content-controlled commercial desktop spreadsheets and checking loops within SAS analysis software were developed for data sets of kelp forest biota with guidance from O'Brien (O'Brien and Harrer 2008). Fully processed data that have undergone appropriate quality control and quality assurance are place in the "final" areas of the SBC data server. The information manager also advises on conventions for handling sampling sites and taxonomy, and guidance for file organization

Currently, all SBC data are published as ASCII tables, which are most appropriate for long-term archival. Delivering data in multiple formats (as suggested by our 2009 Midterm Review panel) has not been identified as a high priority by NSF or the LTER Network and is currently beyond the scope of our IM resources. We are developing management workflows for new data formats to facilitate efficient exchange among recently added projects (e.g., GIS and spatial analysis products from recent work in fire-affected watersheds).

Recent accomplishments

We have made several improvements to the SBC IMS and have integrated these with the SBC website. In particular, new features (c and d below) facilitate cross-links among different areas of our website and accommodate suggestions from the 2009 Midterm Review team. The following information management projects were completed since our 2009 Midterm review:

a) The EML data catalog was decoupled from a local, legacy Metacat system and now draws SBC datasets directly from the LTER Network for display on the SBC website (http://sbc.lternet.edu/data). As part of the migration, EML-dataset templates were redesigned in a "tabbed" format to highlight major sections such as geographic area and methods. The SBC templates are used by other LTER sites (MCR, VCR), the Network Controlled Vocabulary website (http://vocab.lternet.edu), and are being considered for adoption in the redesign of the Network-wide data catalog.
b) Metabase (developed by GCE) was adopted as SBC's database platform. The database was ported from MS-SQL to an open source database.
c) SBC research themes are stored in Metabase, exported in the LTER-project DB XML specification for web display and linked to the personnel directory. The LTER-project schema is based on EML, and is in use at several LTER sites. SBC's project catalog uses the same menus and keywords as those used for datasets to facilitate linkages between SBC research themes and relevant data.
d) Cross-links between personnel profiles and the bibliography were added to the SBC website; site publications can now be filtered by author.

Proposed plans and milestones

Although the SBC IMS currently meets or exceeds all IM requirements for LTER sites, we anticipate that the technological advances and needs for increased synthesis outlined in the LTER Network Strategic and Implementation Plan will require our existing IMS to be modified in the future. In preparation for meeting these future IM challenges we propose to:

a) Use Metabase to produce EML that is efficient to maintain and adapt as requirements for datasets and other material are developed.
b) Standardize SBC data and metadata *content* as appropriate (in addition to already standardized *formats*), to conform to Network practices where and when these exist.
c) Incorporate modular, interchangeable components using code and libraries that are inherently shareable among LTER sites.

These proposed activities and the milestones listed below will help facilitate the smooth integration of the SBC IMS with the ongoing development of LTER Network's Information System (NIS). This integration is dependent on the NIS reaching its own planned milestones. We will continue to be an active participant in the LTER NIS development process and provide feedback to the NIS developers. Since nearly all our information has a web-presence, all milestones listed below will be integrated into the SBC website.

a) **In progress**: All SBC time-series sampling sites have been described in standard format and applications are in development to map these on the website to provide spatial context for research and data. Geographic information will be available as KML, which is appropriate for many external applications (e.g. mapping tools being developed by the LTER Network). *Deliverable:* mapped sampling sites
b) **2012**: Re-build all EML datasets from SBC-Metabase. We began building datasets with Metabase in 2011. We plan to update our time-series datasets in 2012 from Metabase, and upgrade all static datasets to EML 2.1. *Deliverable:* higher quality metadata
c) **2012, 2014**: Submit all SBC datasets to the NIS according to its prescribed schedule. The LTER NIS is currently in development, and two NIS milestones are of particular interest to LTER sites: the development version of the NIS Provenance-Aware Synthesis Tracking Architecture (PASTA) is scheduled to be available in mid-2012, with the production system planned for release in 2014. We will submit all of our datasets to the NIS at both these junctures. *Deliverable:* data in PASTA
d) **2015**: Expand the content of SBC's projectDB to include details of specific research projects and sampling activities. *Deliverable:* website cross-links between research, data, sampling sites and/or publications.
e) **2016**: In order for successful synthesis to occur at a Network level, sites will need to have described their measurements in such a way that these can be compared using automated

tools, and/or registered their measurements with network data synthesis research projects. The most straightforward method is to first standardize measurements at the site level with complete descriptions (including methods, precision and error). We will work with the LNO and the LTER IM community as we standardize our measurements in anticipation of this becoming a LTER Network wide requirement. *Deliverable:* standardized attributes

Related projects

SBC information manager O'Brien currently chairs LTER Information Managers' Committee (IMC, http://im.lternet.edu), and has served on numerous IMC working groups. She is also a member of two NIS Tiger Teams and the LTER Network Synthesis Data Committee (http://intranet.lternet.edu/committees/synthesis-data). We are uniquely positioned to participate in several LTER Network IM and other community-wide projects due to our expertise with EML/XML, our proximity to the NCEAS Ecoinformatics Program, and our association with MCR LTER. We have been most active in the following areas:

a) Development of the LTER Controlled Vocabulary and its associated web services (http://vocab.lternet.edu). Our work with the LTER Controlled Vocabulary is related to O'Brien's efforts with ontology development with the Extensible Observational Ontology (OBOE) in the Semtools project (DBI-0743429, Leinfelder et al. 2011). This work also has the capacity to inform similar ontology development at the Network level, for example, in data discovery or the description of standardized measurements, and will also facilitate interoperability with systems beyond the LTER Network, such as the Biological and Chemical Oceanography Data Management Office (BCO-DMO), and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. Hydrologic Information System (CUAHSI HIS).
b) Quality and usability of EML datasets through the EML Best Practices, and EML Congruence Checker and Metrics. The work with EML dataset quality stems mainly from our use of EML-centric code in the SBC EML Data Query tool, which has been in use since 2006 (Leinfelder et al. 2010). This code library was developed by the NCEAS Ecoinformatics group and is also a component of the LTER NIS PASTA Data Manager. Additionally, our use of EML in the SBC LTER bibliography was reviewed by the EML development community and contributed significantly to the enhancements now available in the EML schema version 2.1. Our work with LTER-project XML, based on EML and co-led by O'Brien and C. Gries (North Temperate Lakes LTER), is likely to do the same.
c) The development of an open-source implementation of the GCE LTER Metabase with MCR, which has proven to be a useful and adaptable component of LTER site data management. This implementation and the resulting collaborations with GCE and CWT exemplify how LTER sites with diverse IM infrastructures can effectively share IMS components.

References

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SUPPLEMENT 3 - SITE MANAGEMENT PLAN

GOVERNANCE

SBC is directed by an Executive Committee chaired by lead PI Dan Reed and includes Co-PIs Sally Holbrook, John Melack, and Dave Siegel and three Associate Investigators. The PI and Co-PIs will serve on the Executive Committee for the entire six-year funding period. The Associate Investigators on the Executive Committee are rotating positions that are filled by individuals with lead roles in short-term (i.e., 2-3 year) studies that are ongoing at the time of their appointment. Since its inception SBC has incorporated a philosophy of shared governance in which strategic planning pertaining to the project's research direction, resource allocation, administrative policies and staffing are discussed at regularly scheduled meetings (monthly during the academic year) that are open to all investigators, postdoctoral scientists, graduate students, the Information Manager and Outreach Coordinator. Lead PI Reed chairs these meetings and sets their agendas with consultation from the Executive Committee. The meetings serve to keep participants informed of the project's broad range of activities, which aids in coordination and integration of the different project components. This management style has been very effective in instilling a culture of shared ownership, enthusiasm and pride for the project among its participants.

PROJECT MANAGEMENT

Day to day management of the project is overseen by PI Reed with assistance from a 25% time Project Coordinator (Associate Investigator Dugan). Management activities include: (1) coordinating the activities of different research groups to maximize efficiency and integration, (2) working with the Outreach Coordinator and SBC investigators to integrate and promote the project's research and education activities, (3) facilitating the transfer of data and other information from project personnel to the SBC Information Manager, (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. Coordination between research and information management is facilitated by an Information Management System Advisory Committee (IMSAC) chaired by Co-PI Melack. The primary objective of IMSAC is to facilitate SBC's collaborative and synthetic research efforts and improve the quality of resultant synthetic products and datasets.

Three fulltime research staff are employed to maintain the collection of data associated with our long-term measurements and experiments. Graduate and undergraduate students employed on the project assist in these activities. An Information Manager and an Education/Outreach Coordinator round out the project staff. As in previous SBC awards, the allocation of funds will be structured around the primary research themes (Section 2- Proposed Research) with a lead investigator assigned to each sub theme (Table S3.1). A separate allotment of funds will be set aside to cover the costs of project management, core long-term measurements, IM and Education/Outreach.

The coordination of research and the exchange of information and ideas among project participants are facilitated because 22 of the 25 investigators on our proposal are located at UCSB and 2 others are within driving distance (see Biographical Sketches). Informal and scheduled meetings involving investigators, postdoctoral scientists, 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 to which all participants (UCSB and non-UCSB) have access (see Supplement 2 - Data Management Plan). In addition to our monthly project meetings, we hold an annual one-day retreat for all SBC participants and other interested parties to insure coordination across the SBC program and to enhance interdisciplinary discussions. This event is well attended and serves as an excellent venue for information exchange and team building.

INTEGRATION WITH NON-LTER SCIENTISTS

The diverse nature of SBC's study habitats and research themes has attracted a diverse group of scientists (in terms of area of expertise and career level) to work at our site. Unlike several other LTER sites, SBC does not have a formal agreement with a federal agency or non-governmental organization that facilitates collaborations and provides research support. Instead, we rely 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, generating over $18 million from 13 different funding sources in collaborative research projects during the first five years of SBC II. Several non-LTER scientists associated with these collaborations have since established formal associations with SBC and are listed as Associate Investigators in this proposal (e.g., Alberto, Bookhagan, D'Antonio, McWilliams, Raimondi, Roberts and Tague).

Additional integration of non-LTER scientists into SBC research is achieved by developing consortia with non-LTER investigators and organizations to examine environmental issues relevant to consortia members. For example, we are collaborating with the Ocean Margin Ecosystem Group for Acidification Studies (OMEGAS), the California Current Acidification Network (C-CAN), and the Southern California Coastal Ocean Observing System (SCCOOS) to measure parameters of the carbonate system of the coastal ocean. This is part of an effort to understand the consequences of ocean acidification for near-shore marine communities of the California Current Large Marine Ecosystem. Another example of such integration with non-LTER entities is the recent consortium that we formed with scientists from the Bureau of Ocean Energy Management, US Geological Survey, National Park Service and UC Santa Cruz to combine and synthesize long-term data sets from multiple sources to develop an improved understanding of regional dynamics of kelp forest ecosystems and the environmental factors that most influence them (Proposed Research THEME 1A.)

Efforts to increase the participation of under-represented groups are achieved through our ongoing outreach efforts (see Sections 1 and 3) and by our participation in a new event at UCSB called GEMS Preview Day. The purpose of the event is to introduce prospective graduate students to the natural sciences early in their undergraduate careers (GEMS stands for Geography, Earth Science and Marine Science, which are the academic units at UCSB that participate in the program). Students attending the GEMS Preview Day come from historically under-represented groups at the University of California.

PLANNING FOR THE FUTURE

Planning for a long-term project like an LTER 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 Associate Investigators. Eleven of the 21 Associate Investigators listed on this proposal have been added to our project during our current award cycle. Most of these additions (7 of 11) are early to mid-career scientists who offer a potential for a long-term commitment to the project.

The lead PI and Co-PIs of SBC II will be maintained for SBC III with the exception that Co-PI Gaines is no longer associated with the project. There are no plans for a leadership transition during the next six-year award cycle. In the unanticipated event that PI Reed is no longer able to perform the duties required of a lead PI, then this role will be assumed by one of the three Co-PIs as determined by the Executive Committee. All three Co-PIs have considerable lead PI experience and all are willing and capable of leading SBC if called upon.

The UCSB campus lies in the center of the physical study domain of SBC LTER and the long-term continuity of our project relies on recruiting UCSB researchers into leadership positions. The structure of our Executive Committee fosters the participation and mentoring of early to mid-career Associate Investigators in project governance and management, which provides a useful mechanism that aids in leadership transition. Anticipated new faculty positions at UCSB will also aid plans for SBC leadership transition. Departmental FTE plans at UCSB include hiring several ecologists, oceanographers and geographers over the next six years. SBC investigators will be directly involved in the recruitment of many of these positions, and we will actively encourage the involvement of these new faculty in SBC research.

Table S3.1. The roles of SBC Investigators in the research themes and long-term measurements proposed for SBC III. The lead investigator of each subtheme and long-term measurement group is shown in **bold**. Additional information on the expertise of each investigator can be found in their Biographical Sketches.

THEME 1. Biotic and abiotic drivers of kelp forest structure and function

THEME 1A	*THEME 1B*	*THEME 1C*
Reed	**Carlson**	**Lenihan**
Alberto	Miller	Carr
Holbrook	Page	Holbrook
Miller	Reed	Reed
Raimondi		
Schmitt		
Siegel		

THEME 2. Material exchanges at the land-ocean margin

THEME 2A	*THEME 2B*	*THEME 2C*
Melack	**Roberts**	**Dugan**
Cooper	Bookhagen	Melack
Schimel	D'Antonio	Page
Tague	Melack	Schimel
	Simms	

THEME 3. Movement and fluxes of inorganic and organic matter in the coastal ocean

THEME 3A	*THEME 3B*	*THEME 3C*
Siegel	**Miller**	**Washburn**
MacIntyre	Brzezinski	Brzezinski
McWilliams	Melack	Carlson
Melack	Reed	McWilliams
Washburn		Page
		Siegel

LONG-TERM MEASUREMENTS

KELP FOREST	*BEACHES*	*WATERSHED*
Reed	**Dugan**	**Melack**
Holbrook	Page	

OCEANOGRAPHY	*REMOTE SENSING*
Brzezinski	**Siegel**
Washburn	Roberts
Hoffman	