**Santa Barbara Coastal LTER III**

**3rd year review**

**Review Panel:**

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**A. Executive Summary**

**1. Intellectual Merit**

*Strengths*: The SBC PI, Co-PIs, investigators and students have been very productive; the work they are doing is being published in both specialty journals as well as more general, conceptual journals. This indicates the SBC project is producing results important for peers working in similar ecosystems, but also that their work is being used to evaluate and test ecological theory. The SBC LTER is rare in its focus on subtidal ecosystems and the inclusion of the understudied beach ecosystem that connects many coastal waters to the land. The review team was impressed by the scale and scope of the research being undertaken. The SBC domain is large and although the kelp forest is the primary ecosystem of study, the coastal ocean and watershed included in this LTER contains diverse habitats. These features present opportunities and challenges that the SBC team has met head on, with research that is conducted across this diverse landscape.

The long-term measurements documenting the community ecology of the kelp forests are particularly compelling and unique to this LTER. The connection to spatial patterns of kelp forest distribution and metapopulation theory are exemplary, we understand that the ongoing genetic and demographic studies will also inform the connection of the kelp forest ecology to larger theoretical concepts. The beach ecosystem subsidy work has the potential to explicitly quantify connections between the land margin and the kelp forest, confronting the challenges of working in the intertidal zone in innovative ways. The work to document the impact of MPAs as well as the watershed efforts to determine the dynamics of fire and drought on discharge and material export is particularly important site-specific work of meaningful interest to local stakeholders. Placing the long term LTER measurements of discharge and fire in the context of longer historical records is likely important here, and we expect there are datasets reaching back earlier than those presented that could help in placing the site-specific work in a larger regional and temporal framework.

Innovative new efforts include citizen science participation in giant kelp mapping to classify LandSat images, and kelp tagging to determine transport patterns. ROMS models to characterize phytoplankton transport combined with spatially explicit mapping of chlorophyll-a over time have illuminated the rapid movement of organic matter across the SBC system. The combination of long term measurements of watershed discharge, nutrients, and suspended solids with downscaled climate forecasts should produce model products that can be used for a variety of ecological studies to determine the impact of land-based forcings on the kelp forest and coastal habitats. We emphasize here the unique nature of the NPP measurements in the kelp forest and the way these measurements complement LandSat estimates of biomass along the coast.

*Weaknesses:*  The panel recognized a tension in the program about whether the real focus of SBC is on kelp forests, or on coastal ecosystems that contain kelp forests. As this concern was also raised by the review panel for the SBC III proposal, this seems to continue as a weakness of the program three years later. Differences in research interests (population and community ecology in the kelp forests; nutrient biogeochemistry and transport in the catchments and coastal ocean) and differences in research training and cultures between the groups leave the impression of lack of integration within the project. An attempt to unify the group by searching for and adopting some common experimental designs and currencies in the watersheds, kelp forests, beaches, plankton communities, and other ecosystem components could help diffuse this tension and result in a more thoroughly integrated team.

Little progress has been made on the quantification of remineralization rates of organic matter in sediments and the subsequent flux of ammonium to the kelp forest. SBC modelling efforts suggest this must play a large role in supplying N to support kelp growth during the summer. This need was highlighted in the proposal, and the justification for such measurements was emphasized during the panel visit, yet these measurements have yet to be completed. This seems to be a key process that must be addressed quickly so that the results can be incorporated into the renewal proposal’s hypotheses and work plan.

**2. Broader Impacts**

*Strengths*: The SBC LTER has had a substantial impact beyond the realm of academic science. A tremendous strength of the project is its education and outreach component. The program has embraced the mission of making the research of the project relevant to society, and they have been successfully engaged in improving STEM education for k-12 students and their teachers. The SBC program has also provided a valuable service to its host institution, UCSB, by engaging undergraduate students. The project has been particularly successful at recruiting a diverse pool of talented undergraduate students into their research projects, education, and outreach activities. The SBC investigators and students are highly engaged with their community and have been active in sharing their results with the public.

Much of SBC’s long term data holdings have served to inform local stakeholders and regional policy decision-makers. Innovative public outreach products include media in the form of mobile phone apps for identification of kelp forest and coastal flora and fauna. The SBC Information system serves as an exemplar within the LTER Network and personnel are actively engaged in efforts that benefit the Network information system and the external IM community.

*Weaknesses:* No deficiencies or weaknesses were identified by the review team.

**B. Body of Report**

**1. Core data collection (five LTER Core Areas):**

SBC researchers are continuing to build on the core long term signature data sets that cover the five core areas of the LTER network: primary production, population dynamics and trophic structure, movement of organic matter, movement of inorganic matter, and patterns of disturbance.

* **Primary production**

Primary production has been well-quantified on the kelp forest reefs through a number of direct measurements and modelling efforts. A major portion of the long-term data collection effort goes towards estimating biomass and rates of primary production of the giant kelp. Chamber flux estimates of the metabolism of the forest understory have been added, and organisms other than kelp that make important contributions to ecosystem net primary productivity are being documented.

*Strengths:* The long-term NPP measurements of kelp are arguably one of the most innovative set of core measurements in the SBC LTER, especially when combined with the LandSat estimates of biomass. Chamber experiments used to determine understory NPP are producing new estimates of whole-ecosystem NPP to place the NPP of giant kelp in perspective.

*Weaknesses:* Primary production in other components of the coastal ecosystem (watersheds, water column, soft-bottom benthos, seagrass meadows, etc) has received little attention, and if the project’s true focus is on coastal ecosystems that contain kelp forests, then these communities deserve more attention.

The allometry and relative growth rate measurements of the accumulation of dry mass of giant kelp may not be easy to compare to the oxygen-based estimates of the understory NPP.

*Opportunities:* We suggest that consideration be given to periodic re-measurement of kelp dry weight conversion factors to insure that estimates of NPP that are dependent on these values are confirmed from time to time with direct measurement. Water column rates of primary production by the phytoplankton are collected as part of other collaborative projects across the SB Channel. Measuring these in the kelp forest itself may be useful in connecting rates by all kelp forest primary producers to trophic transfer studies.

* **Population dynamics and trophic structure**

Guided by the overall conceptual diagram in the 2012 SBC III LTER proposal, the group is tracking populations mostly in the target subtidal kelp habitats and the beaches, while the focus of the watershed investigators on fluxes restricts population aspects of their work to fire disturbance and aspects of invasive species ecology.

*Strengths:* The population and trophic ecology components of the program forge links between the different components of the coastal ecosystem, and provide the ability to evaluate their importance to the functioning of the kelp forest. For example, the subsidy of beach food webs by kelp wrack is a strong subtidal to intertidal linkage (and potentially vice versa) that illustrates how dependent the shoreline infaunal and vertebrate consumer community is on kelp wrack. This has the potential to create an exciting new perspective on cross-ecosystem ecology in the face of climate change. Investigations on the ecology of the kelp forest system are thorough and well focused on key species and important questions across a wide range of appropriate spatial and temporal scales are continuing. The integration of metapopulation theory, current modeling and remote sensing to understand kelp persistence is a shining example of cutting edge science that can be stimulated by the SBC LTER group. More integrative research like this should be encouraged within the group. Another important finding is the group’s discovery that kelp detritus is not an important food source for populations of suspension feeding invertebrates, shifting focus to the importance of phytoplankton. This work has the potential to cause a paradigm shift in coastal marine ecology, particularly if the group continues to test it in other kelp dominated ecosystems of the world. The new work on testing the effect of trait mediated (behavioral) interactions modified by fishing is important and reflects contemporary thinking in ecology.

*Weaknesses:* No deficiencies or weaknesses were identified by the review team. However, while we recognize that considerable effort has already been made toward integration of the various components, some of the linkages are better developed than others.

*Opportunities:*

1. Sponges depend on picoplankton and DOM as food sources, so the current focus on phytoplankton as an alternate to kelp detritus could miss a major trophic pathway.

2. There is a great opportunity to modify the metapopulation models to include effects of demographic and environmental stochasticity which is the way current climate driven population models are going.

3. Using inexpensive video technology (ie Go Pros) to monitor subtidal behavioral experiments could lead to the discovery of key species interactions that help determine ecosystem function.

4. Compound specific isotope techniques were alluded to by investigators and may be a key approach for determining the role of kelp vs phytoplankton organic matter on suspension feeders.

* **Movement of Organic Matter**

Movement and fluxes of organic matter are measured as part of several of the core measurements of the SBC LTER. Within the kelp forest, SBC III has focused on characterizing DOC losses from kelp and continues to attempt to quantify POC export through a series of bagging experiments. These empirical measurements overlap with measurements related to NPP, but ultimately inform a more comprehensive understanding of the contribution of fixed carbon from the kelp forest to the coastal ocean. We were also presented with results from studies where stable isotopes were used to evaluate the relative role of different sources of organic carbon on higher trophic levels, with results indicating a more significant role of phytoplankton and disputing the kelp detritus hypothesis. However, the degree of recycling of this organic matter is clearly a question of interest to the SBC investigators. Measurements across ecosystem boundaries are vital aspect of this research. Modeling efforts are also underway to better understand the transport and fate of phytoplankton as a function of climatic forcings. We understand that organic N and C are measured as part of the watershed flux studies, however these were not presented as part of the midterm site review.

*Strengths:* Of particular note here is the study to address kelp subsidies to beach ecosystems, a vastly understudied question and set of measurements that is being addressed through an innovative series of tagging studies and long term measurements regarding kelp wrack.

*Weaknesses:*  While challenging to address, questions were raised regarding artifacts of the bagging experiments, which retard natural water movement across kelp fronds. As flow underlies a large number of exchange processes in the ocean, effort should be directed to devise a way to incorporate realistic flow regimes into measurements of DOC exudation. Modeling efforts showed some compelling patterns of phytoplankton distribution both across the SB Channel as well as in terms of water mass subduction, however the connection to the ecology of the coastal system has not yet been made (“How much?” has not been answered). Finally, a more complete picture regarding all forms of N and C should be provided in terms of watershed forcings on the coastal ocean – with specific attention here to organic matter and investigator discussions regarding the impact of storms.

*Opportunities:* Potential new approaches to estimating the provenance of sedimentary and dissolved organic matter have been developed and applied in other coastal LTERs, notably the work of Rudolf Jaffe at FCE using fluorescence excitation-emission spectra to identify broad classes of organic compounds with different origins. Application of such approaches could help to determine the importance of watershed sources of DOM in the SBC domain. Fluxes of DON should not be neglected in the work to determine nitrogen sources to kelp

* **Movement of Inorganic Matter**

Core measurements related to the movement of inorganic matter are largely focused on measuring nutrient loads and suspended solids from the watershed to the coastal ocean. These measurements depend on careful measurements of inorganic matter delivery during storm events, which complement modeling efforts using the RHESSys and HRR models. Focused campaigns have also resulted in estimates of beach contributions to nearshore DIN supplies and efforts to determine DIN supply to kelp. Physical oceanography models and observations have been used to estimate the supply of DIN to kelp forests from oceanic sources.

*Strengths:* SBC researchers are utilizing existing long-term data, data collections from focused sampling, and numerical modeling of coastal ocean circulation to investigate the question of how oceanographic processes act to influence freshwater runoff plumes, nitrogen recycling and efflux from benthic sediments, and the fate of net primary production by phytoplankton. The review team was impressed with many aspects of the research presented, including the amount and the quality of modeling of physical processes that potentially drive ecological change and connect physical processes to the flux of matter.

The beach pore water study combines radon estimates of residence times with longitudinal transects of porewater DIN in an innovative way to estimate this flux from the beach ecosystem. The watershed gauging efforts are comprehensive and especially important given the storm-driven nature of nutrient inputs from these systems.

*Weaknesses:* Although research is focused on detailed process understanding and modeling of freshwater transport and dispersion mechanisms, there has been little significant progress to date on nitrogen recycling and efflux from benthic sediments or on understanding whether terrestrial inputs of nitrogen via sediment loading and suspended particulates has an influence on phytoplankton production. Indeed, future research described to the review team includes these measurements, but there was concern that there was not more progress regarding these questions. The review panel was also concerned about how the modeling efforts were underutilizing long-term records and measurements to inform their modeling or to make comparisons regarding how well their models reproduced *in situ* observations.

Fluxes of DIN from the beach have been normalized to various volumes of adjacent nearshore water, however the absolute magnitude of these fluxes have not been contextualized with inputs – even though wrack estimates exist. How much of the organic N delivered by kelp forest subsidies is lost via DIN fluxes back to the coastal ocean? The focused effort on determining mechanisms influencing nitrate and ammonium availability deserves more careful consideration of N cycling, with some perspective regarding nitrification, denitrification, and relationship to oxygen availability (perhaps as influenced by benthic microalgae). Finally, the fluxes from the land to the coastal ocean have not yet been put in the context of simple budgeting exercises which could help to determine the relative quantifiable importance of these sources. We acknowledge these weaknesses were already identified in the panel summary comments on the original proposal, however we do not feel these were adequately addressed in the mid-term review.

*Opportunities:* 15N and 18O isotopes of nitrate in the kelp forest could prove fruitful as a means of documenting relative recycling of nitrogen. Carrying out sediment core incubations from sediments adjacent to kelp forest reefs to measure DIN and DON fluxes as well as denitrification would better inform the N source question for kelp. Even if the porous nature of the sediments would predict low rates, quantifying these values will help close the loop on the ammonium question.

* **Disturbance Patterns**

The central hypotheses of the SBC LTER are concerned with the way disturbances interact with top-down and bottom-up drivers of ecosystem structure and function. In particular, the team has focused on documenting the disturbances caused by the removal of biomass from the kelp forest by waves, and by fires and floods in the catchments changing the delivery of nitrogen and sediments to the coastal ocean.

*Strengths:* The role of disturbance in structuring the ecological communities and in influencing the inputs of materials into the ecosystem is an explicit, main focus of SBC LTER. Disturbance patterns are being directly quantified (e.g., removal rates of kelp from the reef, effect of fire on nutrient cycling in catchments, etc) as well as estimated from models. Effects of disturbance are also being quantified through experimentation (e.g., long term kelp removal as a test of increases in storm frequency, change in food web structure as a result of human fishing pressure). This emphasis allows science done at SBC to be used to address important theoretical ecological questions, such as the importance of metapopulation dynamics in resilience of ecosystems to disturbance and the role that disturbance plays in setting the context for the importance of top-down and bottom-up structuring forces in the ecosystem.

*Weaknesses:* The panel would like to see a more explicit prediction of how changes in disturbance patterns will alter the delivery of materials to the coastal ocean, the rates of cycling of nutrients and carbon within the system, and the resulting changes in community structure and function.

*Opportunities:* We see the predicted developing El Niño as an unparalleled opportunity to test the overall conceptual basis of the proposal that climate forcing can drive ecosystem functioning in the coastal system. We suggest that the SBC LTER group convene a workshop involving both the catchment scientists and marine ecologists to formulate the expected effects of the El Niño. These hypotheses could then be explicitly tested by following the system performance in the coming year. Such an exercise could help focus the renewal proposal, acting as a winnowing process by identifying the most important drivers and pathways of change in the coastal kelp forest and providing a justification for de-emphasizing pathways in the current work that played a minor role.

The SBC III proposal review panel also pointed out the desirability of evaluating impacts of ocean acidification on kelp forests. SBC received supplemental funds to purchase instrumentation (pH, O2 sensors) for reef monitoring, however little has been done as yet with these new data streams and possible OA impacts have not been incorporated into the guiding conceptual models of SBC.

The research group should remain vigilant for potential effects of prey release created by sea star wasting disease. While some studies are being conducted, the impacts of invasive macroalgae on giant kelp communities may increase in the coming years and may need to be expanded.

**2. Compelling, site-specific, long-term ecological and related research**

The long-term measurements documenting the community ecology of the kelp forests are particularly compelling and unique to this LTER. The connection to spatial patterns of kelp forest distribution and metapopulation theory are exemplary, we understand that the ongoing genetic and demographic studies will also inform the connection of the kelp forest ecology to larger theoretical concepts.

*Strengths:* The beach ecosystem subsidy work has the potential to explicitly quantify connections between the land margin and the kelp forest, confronting the challenges of working in the intertidal zone in innovative ways. The work to document the impact of MPAs as well as the watershed efforts to determine the dynamics of fire and drought on discharge and material export is particularly important site-specific work of meaningful interest to local stakeholders. Placing the long term LTER measurements of discharge and fire in the context of longer historical records is likely important here, we expect there are datasets reaching back earlier than those presented that could help in placing the site-specific work in a larger regional and temporal framework.

*Weaknesses:* No deficiencies or weaknesses were identified by the review team.

*Opportunities:* Although the group is publishing in top ecological journals, there is still an opportunity to use the existing data bases and to modify field work to test more ecological theory, which would help generalize their findings. A partial list of theoretical tie-ins includes:

1. Diversity – resilience theory - using taxonomic species richness, diversity, and functional diversity of the entire (algae, invertebrates) benthic community to examine the extent to which diversity predicts resilience to various storm and ENSO disturbances.

2. Productivity- diversity theory– using productivity as the independent variable, and diversity as the dependent variable to determine the shape of the relationship (if any) across various spatial scales and the underlying mechanisms.

3. Theory of pulsed resource systems – à la Holt - since the kelp forest, beach and terrestrial ecosystems are all pulsed. It is highly unusual to have a study system with this degree of episodic resource supply, providing an opportunity to test the extremes of model predictions.

4. Cross- ecosystem theory – à la Polis et al., with recent developments to motivate questions about how the spatio-temporal configuration and permeability of donor and recipient habitats might affect cross ecosystem subsidies and their ecological consequences.

5. Cumulative disturbance and legacy theory – to guide an examination of potential legacies of past disturbance in the kelp forest and terrestrial plant communities. Cumulative impacts may differ depending on the longevity and life history of key species. This body of theory is being tested in coral reefs and in terrestrial landscapes. For example, responses in the long-term removal experiment could be examined to test this theoretical framework.

**3. Cross-site or broader-scale synthetic research**

*Strengths:* The panel was impressed with the potential of the citizen-science effort for the identification of the distribution of kelp forests (floatingforests.org). Given the very poor worldwide documentation of the distributions of important coastal ecosystems (like salt marshes and seagrass beds), such an approach could be used to rapidly fill in data gaps for large areas of the world.

SBC has had an impact on the management of the marine environment in southern California, especially in the siting process for marine protected areas. Such applications of SBC expertise and data could be better highlighted

*Weaknesses:* While SBC is working closely with MBR and CCE, there are other coastal LTER sites that seem to be natural sites for cross-site work, and the panel urges the group to reach out to other LTER sites. For example, there has been extensive cross-site work on the characterization of the sources of DOM in coastal systems that could benefit the SBC, and the kelp forest community ecology questions and techniques could augment efforts at other coastal sites.

Incorporating more ecological theory into the research would increase the opportunities for synthesis. The group is unusually well poised to use the oceanographic current model further to test hypotheses about dispersal and metapopulation dynamics of other coastal marine species as they relate to the population persistence and connectivity in and out of MPAs. These findings could be generalized by testing them in other areas.

There are a few good examples of SBC cross site collaborations such as the kelp–detritus and beach armoring work. More cross site collaborations like these should be encouraged.

*Opportunities:* Possibly the largest synthetic contribution the SBC LTER group could make lies in the arena of ecosystem responses to physical forcing related to climate change. The Byrnes et al 2011 paper on storminess and food web complexity is an excellent example. Although climate is a driver identified in the conceptual model of the SBC III proposal, more integrative links between climate and changes in populations and communities could be made throughout the body of SBC LTER research. For example: Does climate driven kelp loss affect trophic cascade strength in and out of MPAs ?

**4. Outreach, education, training, benefits to society**

The review team was very impressed with the Education and Outreach components of the project. The partnership with the established UCSB Research Experience and Educational Facility (REEF) was impressive and provided a direct connection to the research the LTER program is doing with not only undergraduate involvement, but also public outreach. SBC’s Schoolyard program is highly successful in involving local K-12 programs. These outreach efforts include developing a bilingual book for the LTER Schoolyard Book Series that highlights giant kelp forests and sandy beaches. SBC has leveraged marine lesson science plans developed at other institutions and adapted them to fit curricula that meets California State Science Standards, Common Core Standards and the Next Generation Science Standards. The NSF funded Math-Science-Partnership “Pathways to Environmental Literacy”, which involves 4 LTER sites to utilize LTER research in professional development of middle school science teachers appears to be highly effective. The panel believed that other exciting avenues for outreach included the aid in the development of the iPhone apps for tidepool, kelp, and sandy beach ecosystems. These efforts have been extremely successful in involving both graduate students and undergraduates in outreach efforts to the local community and beyond.

Since the time of the proposal renewal, 10 postdoctoral fellows and 41 graduate students have received funding or been involved with the LTER program. The involvement of undergraduates in LTER research was found to be exceptional, including 11 REU students and 213 additional undergraduate students who have participated in SBC research. This is remarkable given the limited resources provided by LTER funding and signifies excellent leveraging of additional funds as well as broad participation in the LTER program across the university and elsewhere.

Although all programs struggle on how to do this effectively, a mechanism for assessment of learning outcomes and tracking of students (in both REU and K-12 programs) involved in outreach is critically important. The panel recognized and were impressed with the current efforts of Scott Collins to pursue assessment activities and the panel would like to highlight the importance of this continued work.

*Strengths:* The SBC LTER Investigators and students are actively engaged with their community and have been active in sharing their results and participating in policy issues concerning natural resources, coastal management, and land use. This includes planning for and the design and efficacy of marine protected areas, working with the California Coastal Commission, and the Channel Islands National Marine Sanctuary to name a few. The broader benefits to society were found to be excellent by the panel.

*Weaknesses:* There were no substantive weaknesses of the outreach, education and broader benefits and found the SBC LTER to be an excellent example of how well outreach can be integrated into LTER research. During the review panel discussion with the graduate students, it seemed like many students were not aware of the ongoing outreach efforts or potential opportunities to get involved.

*Opportunities:* Although not a criticism, the panel suggests that the PI’s and outreach coordinators make a more concerted effort to inform the LTER graduate students of outreach activities and how they may be able to get involved. A second suggestion is for the Education and Outreach team to develop and administer data management curricula. This activity would take advantage of SBC’s access to large numbers of undergraduate and graduate students, who contribute to the corpus of LTER research data.

**5. Information Management**

The SBC LTER website (sbc.lternet.edu) is the primary point of access for research information, associated data, and educational resources. Information on this site is complete, well organized, and suited to a variety of end users. Data are browseable through a number of avenues to facilitate discovery by scientific users, however some reviewers found it difficult to discover desired datasets via category searches. The SBC LTER IMS effectively leverages existing capabilities of the UCSB Marine Science Institute (e.g., connectivity, and backups). The IMS meets or exceeds LTER Network requirements for data access, and all data from SBC research have been contributed to PASTA. SBC LTER IM team has been responsive to review concerns and is in the process of creating better linkages between information components of the SBC LTER website. This could be expanded to link datasets to publications and personnel, however it is recognized that this activity needs to be strategic to prevent proliferation of ineffective looping connections.

*Strengths:* The SBC Information Management System (IMS) has been highly successful at meeting the needs of its scientific community through close interaction with investigators, pro-active innovation, and rapid response to emerging LTER Network requirements. The IM team is forward-looking and collaborates across LTER sites (e.g., MCR and GCE) to make use expertise, existing technologies and methodologies where possible (e.g., adoption and migration to metabase). The SBC Information Manager is integrated into many activities at the Network level, and is engaged in development of new protocols, and best practices within LTER and externally.

*Weakness:* The one IM deficiency found was a lack of access to model research results. The Review Team recommends that the Information Manager discuss strategies and solutions with SBC model investigators to determine an approach that best supports SBC science goals and satisfies requirements for discovery and access of SBC research results.

**6. Project management, including institutional relations, personnel management, decision making, diversity, leadership and transition plans**

*Strengths:* The project’s PIs are thoroughly committed to SBC, and they all serve as permanent members of the project management team. New viewpoints and expertise are incorporated into the management of the project by the inclusion of three rotating members of the leadership team who represent areas of current emphasis of the project. This structure allows for consistency of vision and policies for the duration of the project. As all the PIs are senior faculty at UCSB with apparently close relationships with the administrators at the university responsible for providing the resources necessary to accomplish the project. There is disciplinary breadth among the PIs.

*Weaknesses:* Three of the 4 current PIs have been cover page PIs on all three SBC proposals, and all 4 of the current PIs were also PIs on SBC II. This could be an issue because it could limit the incorporation of new ideas into SBC in the future, and it does not show a planning for succession in the leadership of the program. Thought should be given to adding a younger investigator to the group of PIs in the renewal proposal that would bring strength for the new directions that will be proposed for the next phase of SBC.

*Challenges:* Support of a state of the art analytical chemistry lab is crucial to the goals of the SBC LTER. This has been a challenge for SBC investigators, with inconsistent funding and support for staff scientists. A minimal investment to bring back stable isotope capability seems necessary for the future success of the program. A taskforce investigating models for the future of this support service is underway but we underscore here that this is a critical element for research of the SBC LTER.

**7. Collaborations (Formal, informal and new partners)**

The Review team was introduced to an impressive array of collaborators, underscoring the ways in which the long term measurements of the project have been leveraged for other research, examples of projects that are complementary to the goals of the 2012-2018 proposal, and efforts that may provide opportunities for collection of parallel long term datasets. In total, $11.5 million of additional research dollars have been raised on projects related or dependent in some way on the SBC LTER in the past three years. Informal interviews with investigators on the project also revealed current and future mechanisms for collaborative interactions that are highlighted below.

*Strengths:* We were especially impressed in the way that the Sandy Beach Ecosystem kelp forest subsidy project exemplifies a collaborative effort that truly complements the research goals and questions of the SBC LTER. Carrying out this work provides a clear connection between the land-sea margin that is central to the objectives of the SBC LTER. The NASA funded “Plumes and Blooms” project is also of note in collaborative potential to SBC III of the projects presented to the mid-term review. The “Marine Biodiversity Observing Network” is another collaborative effort, integrating biodiversity data across ecosystems in the region and includes measures collected as part of the SBC LTER. It was most evident to us that the projects providing physical oceanographic data (x,y,z), as well as programs describing organic matter flow (PnB) are of most critical collaborative importance to enhancing the research goals of the SBC LTER

The broad nature of this LTER, its numerous graduate students, and impressive and extensive outreach component has come about largely due to the collaborative culture inherent to this group, and likely a result of working fifteen years on a multi-investigator project of this complexity. The most intense activities related to organizing research focus and designing shorter term campaigns appear to arise during proposal writing for each phase of the SBC LTER. A recent graduate student seminar (led by J.M and D.S.) provided an opportunity to create a foundation for students associated with the project and was a highly reviewed approach by investigators and students in providing an integrative presence across the various projects. We suspect that the availability of intermittent quarters of graduate student funding also serves as incentive for investigators to become involved and leverage LTER support as means of supporting students and investigator research.

*Weakness:* The review team feels that a weakness in the mechanisms for collaboration exists in bringing watershed and coastal ocean investigators together in the years between proposal efforts. We recommend that more formal structures be put into place to facilitate discussion of cross-system interactions that may assist in connecting these themes of the proposal. We suggest that this may be accomplished by regular work meetings structured as “charrettes” to accomplish a specific task or tackle a particular cross-disciplinary problem, where the emphasis of meetings is placed on discussion and conceptual modeling or quantitative exercises to resolve connections across system boundaries, for example see our above suggestion regarding an El Niño focused workshop.