

2014-2015 Annual Report to the NASA Biodiversity and Ecological Forecasting Program

Title: Demonstrating an Effective Marine Biodiversity Observation Network in the Santa Barbara Channel

Agreement number: NNX14AR62A

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Date: July 29, 2015

Performance Period: October 1, 2014 to September 30, 2015

Project Goals and Objectives:

Although we spend millions annually monitoring marine resources, these efforts are uncoordinated and have major information gaps. We proposed to develop a scalable and transferable demonstration marine Biodiversity Observation Network (BON) in the test bed of the Santa Barbara Channel (SBC), one of the most monitored marine areas of the world. This BON will network existing monitoring efforts and fill the major remaining information gaps. Our focus on SBC allows us to effectively cover the complete spectrum of biodiversity from ecosystems to microbes within a reasonable scope of funding. This is due to the profusion of existing biological monitoring and research programs by our partners including government agencies, universities and NGOs. Yet there are significant gaps in our knowledge of even this relatively well-studied area, such as microbial diversity. We are testing novel methods for monitoring biodiversity, including automated image analysis and genomics. We will use these methods to fill key gaps in our knowledge of biodiversity, and will also apply these methods to taxa that are well sampled by existing monitoring methods in order to test the accuracy and cost effectiveness of these more advanced techniques. Our overall objective is to provide a complete picture of biodiversity in SBC using a transferable system that integrates and augments existing monitoring programs including the NSF-funded SBC LTER program and the Channel Islands National Park. Broad goals were to:

A. Integrate biodiversity data to enable inferences about regional biodiversity. Synthesizing information relevant to biodiversity will require integrating highly heterogeneous data collected at widely different temporal and spatial scales. We employ advanced techniques in spatial statistics for this synthesis and will provide multiple biodiversity-related data products, including holistic indices that will provide easily interpretable measures of ecosystem health.

B. Develop advanced methods in optical and acoustic imaging and genomics for monitoring biodiversity in partnership with ongoing monitoring and research programs to begin filling the gaps in our knowledge. A key element of our plan is a 'pincer movement' using two classes of methods that approach diversity observation from opposite directions: optical and acoustic imagery from the ecosystem scale down to the species level, and molecular biology from the genetic scale up through community level.

C. Implement a tradeoff framework that optimizes allocation of sampling effort. An effective marine BON will require targeted sampling to address key data gaps, while making best use of existing sampling efforts, thereby gaining a complete description of biodiversity while minimizing cost. Optimal decisions about data collection will require a framework for balancing costs and benefits of alternative sampling. Such a framework will be used to make recommendations for how resources should be allocated in a full-scale BON as a function of the program's goals and anticipated funding level.

In the Cooperative Agreement with NASA, the project agreed to fulfill the following more specific goals.

1. Develop a scalable and transferable demonstration marine biodiversity observation network (BON) in the Santa Barbara Channel.
2. Integrate and augment existing monitoring programs to provide geographically-integrated time-series metrics of biodiversity and ecosystem health, a transferable BON data management system, and a sampling cost-benefit optimization framework useful for designing a BON anywhere.
3. Disseminate products and results from the demonstration marine BON to a wide range of end users from scientists to school children.
4. Develop and implement advanced methods in optical and acoustic imaging and genomics for biodiversity monitoring.
5. Integrate this activity into the international Group on Earth Observations Biodiversity Observation Network (GEO BON).
6. Prepare for, participate in, and respond appropriately to reviews of the project.

7. Participate in scientific meetings or professional society meetings identified by U.S. Government program managers as pertinent to project goals.

8. Inform the relevant U.S. Government program managers of any results nearing publication and the release of final data products so that they might prepare for the announcement and any associated publicity and/or public outreach.

9. Data produced under this cooperative agreement will be available without restriction as to its disclosure, use or duplication except as otherwise negotiated by NASA and the University of California, Santa Barbara. The goal is full and open exchange of data and metadata with minimum possible cost, delay and restriction.

First Year Progress:

Here we describe our approach and progress organized by the three broad goals above.

A. Integrate biodiversity data to enable inferences about regional biodiversity.

This project will analyze patterns of biodiversity in the Santa Barbara Channel, describing how different aspects of biodiversity have changed over time and how they vary across space. These analyses will focus on both new and existing observations, as we are combining data generated by our genetics and image analysis with existing data from long-term biodiversity monitoring in the region. In year 1 we have acquired and integrated biodiversity data from a range of sources into a synthetic dataset for analysis. We have focused in particular on nearshore communities for which we have assembled data from 173 sites monitored by 4 different programs, many of which have 30+ year data series. These datasets document abundance of more than 350 distinct taxa including fish, invertebrates and algae. To facilitate data synthesis, we have been developing a taxonomic database to enable comparison of biodiversity data from different sources. The taxonomic database is scalable to accommodate the integration of additional data sets. Biodiversity datasets that will be added in the next year include data from deep-water benthic sampling, data from open water plankton sampling, and data from ichthyoplankton sampling. Specific data that we have acquired include the following:

NPS Kelp Forest Monitoring (KFM)

- 37 sites across Channel Islands (San Miguel, Santa Rosa, Santa Cruz, Anacapa, Santa Barbara, and San Clemente Islands)
- Annual sampling from 1982 to present
- 118 distinct taxa
- Benthic density, benthic cover, fish density data, fish size-frequency, kelp tagging, subtidal temperature

Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)

- 118 sites across Southern California Bight
- Varied sampling from 1999 to present
- 131 distinct taxa
- Benthic density, benthic cover, fish density, fish size-frequency

San Nicolas Island (SNI)

- 7 sites around San Nicolas Island
- Biannual sampling from 1980 to present
- 325 distinct taxa
- Benthic density, benthic cover, fish density, kelp tagging

Santa Barbara Channel Long Term Ecological Research (SBC LTER)

- 11 sites distributed on the mainland and north side of Santa Cruz Island
- Annual sampling from 2000 to present
- 307 distinct taxa
- Benthic cover, fish density, kelp tagging, subtidal temperature

Additionally, we are in the process of combining the above biological data with physical data. This will allow us to analyze the physical drivers of biodiversity. Because our goal is to use these results to develop regional scale inference about patterns of biodiversity, we focus on physical data for which we have continuous coverage within the region. These data include 1) bathymetry and substrate data derived from sonar surveys, 2) sea-surface temperature, chlorophyll and local kelp canopy derived from satellite imagery, 3) wave disturbance and ocean current data derived from regional models, and 4) data on the shape of the coastline calculated from maps. Processing and integrating physical data is underway and should be concluded in the first quarter of year 2.

We hired a data specialist, Jacob Staines, to acquire and integrate the above data in ways that are sustainable into the future (clearly annotated code, versioning, full metadata). MBON postdoc Thomas Lamy started July 1, 2015. Prior to joining us, Dr. Lamy was a postdoc in the lab of renowned spatial statistician and ecologist Pierre Legendre, University of Montreal. Lamy is interested in developing predictive models of marine biodiversity using physical and biological data derived from remote sensing. In collaboration with Dr. Brian Kinlan, a marine spatial ecologist with the NOAA Biogeography Branch, we (Miller, Rassweiler, Reed) leveraged MBON to obtain NOAA funding for an additional postdoc. That person will be recruited in fall 2015 and will work on developing species distribution models to relate physical and biological data.

SBC BON Remote Sensing

Remote sensing data are critical for scaling up local observations of biodiversity and for relating physical and ecological variables to marine biodiversity. The SBC mBON is focused upon three activities linking remote sensing to observations of marine biodiversity. These build on on-going NASA and NSF supported projects

and span both subtidal and pelagic environments. Specifically, the remote sensing component of the SBC BON is focused on:

- The remote sensing of giant kelp populations and the application of these products to answer ecological and biodiversity questions
- The analysis of satellite ocean color observations using novel ocean color inversion approaches, and
- The analysis of planktonic biodiversity indices from the Plumes and Blooms (PnB) time-series study applied to SBC BON genomics observations.

Accomplishments from all three of these components are reported in this annual report.

Both multispectral and hyperspectral remote sensing of giant kelp canopy fronds are used to help answer ecological and biodiversity questions for the SBC BON. In collaboration with the Santa Barbara Coastal LTER we have assembled a Landsat giant kelp (*Macrocystis*) canopy biomass time series from 1984 – present, spanning its dominant range in the NE Pacific (San Francisco, CA to Punta Eugenia, Baja California Sur, Mexico). This dataset has recently been used to determine the geographical variability and non-linear response of the environmental controls of giant kelp biomass dynamics (Bell et al. 2015a), as well as a test of metapopulation theory, showing that well connected patches had high probabilities of colonization and lower probabilities of extinction (Castorani et al. 2015). Presently, this dataset is being used to identify large-scale biogeographic population clusters using seascape genetic approaches (Johansson et al. in review). Multiple hyperspectral images of the SBC are being collected as part of the HypsIRI Preparatory Airborne Campaign. Empirical relationships between laboratory reflectance of giant kelp blades and their physiological state (Chl:C) have been developed and applied to hyperspectral images captured by the AVIRIS sensor. These images have shown that the physiological state of the canopy is positively correlated to the depth of the reef where the kelp plants attach, and may have implications for measuring the productivity and age structure of kelp forests (Figure 1; Bell et al. 2015b). Tom Bell, a student in the Siegel lab, is leading this work.

More than 13 years of NASA satellite ocean color observations are used to characterize the controls of space-time variability of optical properties of the Southern California Bight (SCB). Specifically, we are to understand how changes in chlorophyll concentrations (chl) and particulate backscattering coefficients (bbp) co-vary over time and space. Level-2 spectral ocean reflectance data from SeaWiFS, MODIS and MERIS satellites are merged spectrally following procedures developed by Maritorena et al. (2010; RSE) using the GSM semi-analytical algorithm to simultaneously retrieve values of chlorophyll concentration and particulate backscattering coefficient at 443nm. Validation between retrieved

parameters and Plumes and Blooms field data is encouraging (e.g. $r^2=0.40$ for bbp). Results thus far show the importance of upwelling, relaxation and storm events in determining optical variability over time, and the role of episodic events in driving general patterns of distribution is apparent. Chlorophyll and backscatter seem very well correlated in offshore waters, while the relationship breaks down within ~15km from the coast. The role of re-suspension of materials, upwelling conditions and photoacclimation in affecting the predictability of the bbp:chl relationship throughout the SCB will be addressed. The importance of the large/submesoscale components of particle variability for determining nearshore productivity will be assessed. Fernanda Henderikx-Freitas, a student in the Siegel lab, is conducting this work. We will also collaborate with Maria Kavanaugh (WHOI) in applying these data with her seascape characterization approaches for mapping marine biodiversity indices.

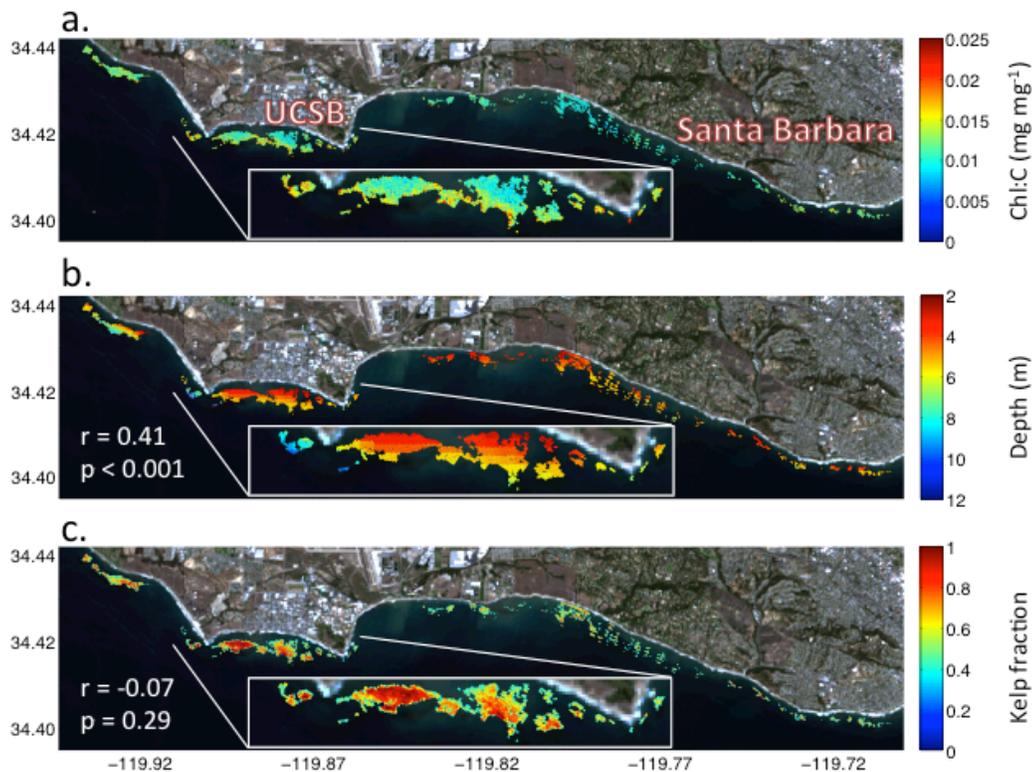


Figure 1. Map of the distribution of (a) estimated Chl:C in the surface canopy (b) depth and (c) kelp pixel fraction of Santa Barbara area kelp forests on April 11th, 2013. Insets show magnified data of the Isla Vista kelp forest and reef. Data for a. and c. from AVIRIS hyperspectral images, and b. from NOAA National Geophysical Data Center coastal relief model (Divins & Metzger, 2009).

The goal of the Plumes and Blooms (PnB) study is to assess and model ocean color changes in a complex coastal site and is supported by the NASA Ocean Biology and Biogeochemistry program. PnB conducts monthly day-long cruises at 7 stations crossing the Santa Barbara Channel (~45 km long transect). At

each station, measurements of ocean color spectra, inherent optical properties, phytoplankton pigment, dissolved and particulate carbon, and macronutrient concentrations, and particle size spectra are measured. Samples are also collected for particulate DNA for both prokaryotic and eukaryotic (Emma Wear et al., work in progress). Our eventual goal in the SBC mBON is to statistically relate bio-optical information of planktonic biodiversity from the PnB measurement suite (phytoplankton pigment concentrations, phytoplankton absorption spectra, etc.) with signatures from the SBC mBON genomic work. We will be working with Emma Wear, a graduate student in the Carlson laboratory, to compare genomic indices of prokaryotic biodiversity with the PnB bio-optical data. Also a new student, Dylan Catlett, is coming into the Siegel laboratory to continue this work. He will be working with Profs. Siegel, Carlson and Iglesias-Rodriguez in this work.

B. Develop advanced methods in optical and acoustic imaging and genomics for monitoring biodiversity.

Optical imagery - field

We have used an SLR with 14mm lens mounted on a rigid frame (quadrapod) to image shallow benthic and kelp forest communities at 14 reef sites spanning the Santa Barbara Channel, including several Channel Islands National Park monitoring sites, as well as seven offshore oil platforms. In deep water, we have obtained still imagery data collected from a SeaBED class autonomous underwater vehicle (AUV) that surveyed the benthos in the Santa Barbara Channel region. Transects were conducted on two seamounts known as the "Footprint" and "Piggy Bank." Elizabeth Clarke, who leads the AUV program at NOAA NMFS NWFSC in Seattle WA, provided the data and will be collaborating with us as we move forward.

The SeaBED AUV is a hover-capable robotic vehicle that is able to work as close as 2 m off the seafloor while maintaining precise altitude and navigation control. Its 2,000 m depth rating makes it an ideal tool for conducting surveys of reef, shelf and deep slope habitats. Its small footprint allows it to be operated from platforms ranging from global class oceanographic research ships to small vessels of opportunity. The SeaBed AUV can carry a wide variety of optical, acoustic, and oceanographic sensors for non-extractive surveys of the benthic communities in habitats that are too deep for divers and surface acoustics and too rugose for towed camera sleds and traditional bottom trawling.

The AU data was collected during a "comparison cruise" in 2011. The objective of the cruise was to survey fish using the SeaBED AUV, the Dual Deepworker submersible, and an ROV coupled with fish detecting hydroacoustics and to compare the abundance, size distribution, biomass and diversity estimates from the different platforms to understand the capabilities of the different technologies and methods to assess West Coast groundfish populations in untrawlable areas.

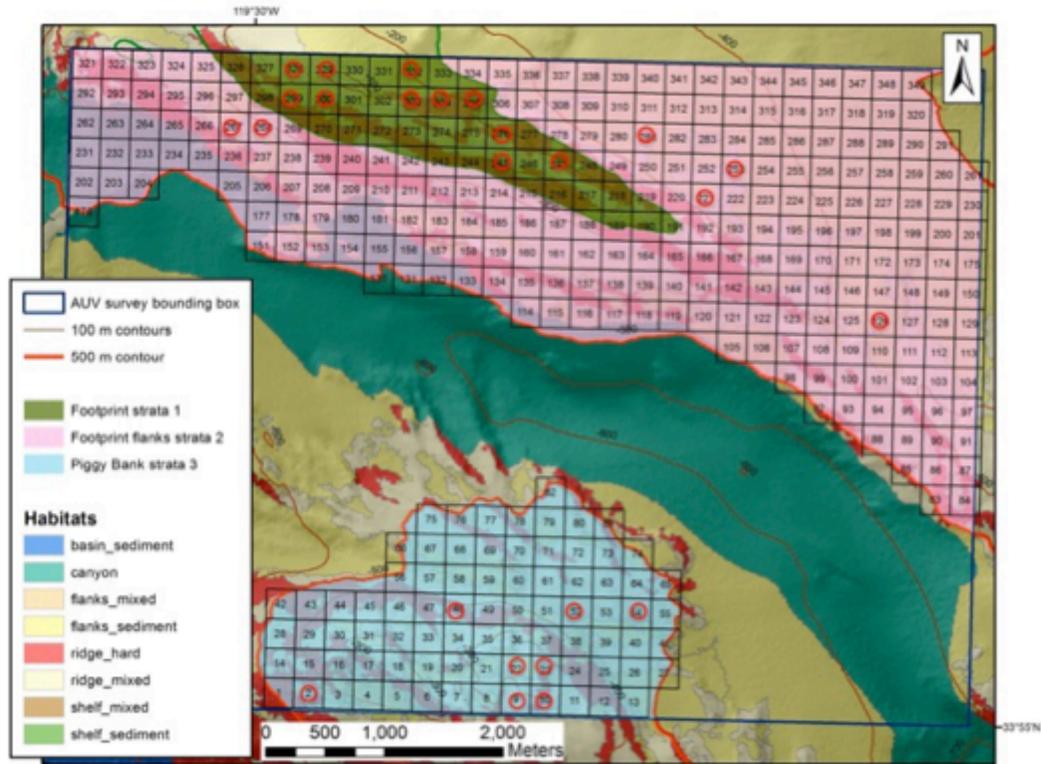


Figure 2. Locations (○) of the 25 survey blocks sampled in SBC using the SeaBed AUV.

The Piggy Bank is about 30 km² in area, ranging in depth from 275 to 900 meters; the Footprint Bank is about 10 km² in area, ranging in depth from 80 to 500 meters. The underwater visual surveys were planned to span from 400 m to the top of each seamount. The imagery includes stereo pairs that can be used to estimate size and biomass of organisms.

Image processing

During the first year we have performed extensive research on image analysis techniques targeted at underwater image classification on the operational level. Our main interest was in finding techniques that could be trained automatically based only on provided training data and thus could be deployed automatically in our cloud-based image analysis and annotations system BisQue. Such techniques would have to overcome the complexity inherent in the multitude of existing image feature descriptions and classifications techniques. During this period we have explored several feature aggregation techniques that would allow automated classification based on a large number of computable feature descriptors and a distributed cloud based system. We have proposed and published in peer-reviewed conferences two novel techniques: 1) feature

aggregation based on a CRF modeling of feature dependencies and 2) K-NN classification using dropout regularization.

During these studies we have used the extensive dataset of >2000 underwater images acquired during the shallow benthic field effort described above and manually annotated for percent coverage of sessile species in the BisQue system. Each image contained 100 annotated locations amounting to 200K data points with over 30 species. We have obtained very encouraging results on automated identification of the 11 most abundant classes (over 80% of data points) with classification accuracy of over 85%.

We further explored state of the art deep learning techniques using Convolutional Neural Networks on the same dataset and obtained comparable results. The major advantage of these techniques is that CNNs learn image features automatically (in convolutional layers) and operate directly on image pixels that can be efficiently accessed via the BisQue system. The major disadvantage is the computational complexity that requires use of the latest GPUs. We have used a very popular CNN library “Caffe” running on an nVidia K20 GPU and observed training times of 14 hours for the aforementioned dataset. This study, yet unpublished, will lead to the implementation of the automated classification module for the BisQue system, for which we are planning on utilizing an nVidia K40 GPU based server already acquired for another project.

BisQue extensions

In the past year we have also done extensive work on the cloud based image analysis system BisQue to enable better annotation of existing data and faster operation for the classification framework. Our main improvement was in accelerating and improving scalability of image services that are accessing pixel data in various formats and give pixel access for the analysis modules. For the case of percent cover based classification, the image service is accessing original 14 bit RAW image data and produces small 8 bit image patches for training. In this update various image operations were sped up by approximately 2-5 times.

We have also finished several User Interface improvements extending graphical annotation capabilities and summarization of annotated data. Improvements include full support for GeoTIFF imagery with export to GeoJson and KML, support for Homographic geometrical transformations of the percent cover annotation grid (helps annotating sub-regions of images), occurrence statistics of graphical annotations and various other improvements.

Acoustics

Using the Channel Islands National Marine Sanctuary vessel Shearwater, Hildebrand’s lab successfully serviced two high-frequency acoustic recording packages (HARPs) in the Santa Barbara Channel in June. Both instruments

returned good acoustic data for the time period Feb-June. Hildebrand's lab at Scripps will be analyzing the data in the coming year to generate occurrence data for marine mammals in the SBC.

Genomics

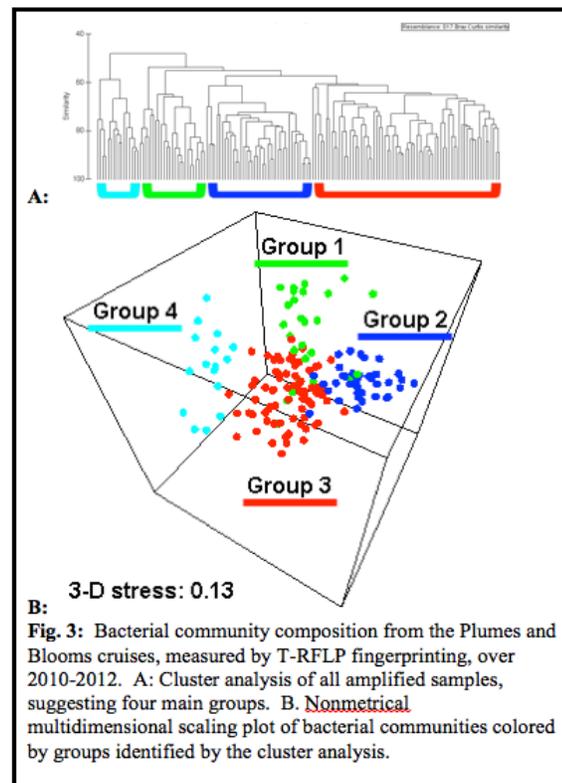
Taxonomic identification of microorganisms has traditionally been challenging because, in addition to limited morphological characteristics, less than 1% of the microbial diversity has been cultured successfully. The introduction of genomic approaches over the past two decades has allowed microbiologists to overcome these limitations and assess microbial diversity in terrestrial and aquatic ecosystems. The use of genetic markers with high-throughput Next Generation (Next Gen) sequencing provides high-resolution taxonomy for phylogenetic analyses as well as data for biogeographical distributions of marine microbial plankton.

Identification of metazoans has traditionally been based on morphology, which suffers from well-known limitations including phenotypic plasticity, morphologically cryptic taxa and life stages and the need for taxonomic expertise. In response, the use of DNA 'barcodes' has been increasingly adopted for the study of biodiversity. There are several genetic markers that can be used but the most common is mitochondrial cytochrome oxidase subunit I (COI), which has been successfully used for the identification of fish, crustaceans, protists, and many other organisms.

We proposed to build on existing sampling efforts to implement a sustained DNA collection program to be used for metabarcoding and eDNA analyses.

Prokaryotic and eukaryotic microplankton

Field sampling. We are using a rosette equipped with 10L Niskin bottles to collect several samples from discrete depths along the PnB transects in the SBC. *In situ* pumps (McLane) will enable collection of much larger-volume samples (10s – 100s of liters) for assessing diversity from discrete depths and depth-integrated samples. McLane pumps will be acquired in the next year using



BOEM funding that arrived at UCSB July 18. Three in-line filter holders will allow simultaneous collection of three separate size fractions of plankton (0.2- 5 μm , 5 – 53 μm and > 53 μm).

Sequencing and planktonic diversity analysis. We already have a 4-year time series of filter samples in hand from the PnB transect, which PhD candidate Emma Wear is currently preparing for sequencing, phylogenetic analysis and assessment of spatial and temporal patterns. These samples were collected approximately monthly from March 2010-Sept. 2014, and DNA was collected from ~600 0.2 μm samples and ~500 1.2 μm surface samples at all 7 PnB stations, from 75 m at deep stations (2-6), and from a profile at the central Station 4 (0, 30, 75, 150, 300 m). Currently 0.2 μm samples from 2010-2012 have been analyzed using tRFLP (Wear et al 2015). This analysis revealed patterns of microbial community structure associated with different conditions including recently upwelled water and seasonal patterns. Next gen sequence analysis will provide higher fidelity though which we will extend interpretation of these patterns. Extensive ancillary data is available for these samples through PnB, including DOC, pigments, nutrients, etc. Ultimately, the objective here is to determine if there are repeatable temporal patterns in bacterial community structure and how that may be linked to biogeochemical variability as well as ocean color and coherent seascapes.

We are currently working with Mya Breitbart's Group at USF (Florida BON) to develop a standardized plan for sampling (Filter type, fractionation etc). Common primers and a sequencing platform (Illumina MiSeq) for prokaryotic work have been decided upon. Both groups will use the same bioinformatics pipeline to analyze data. We are also in contact with Stanford's eDNA group (Jesse Port) to standardize e-DNA protocols (water collection, filters, gene targets, primers).

Ichthyoplankton

The goal of this section of SBC BON is to develop and apply genetic techniques to identify larval fishes within plankton samples collected in the Santa Barbara Channel and throughout southern California. At present, many fisheries monitoring programs throughout the world utilize larval fishes to track ecosystem and population dynamics. However, traditional techniques used to analyze the plankton samples are extremely labor intensive, and application of genetic tools has the potential to greatly improve the efficiency of these programs.

The first year of this portion of SBC BON was dedicated to collecting samples and identifying people to hire to work on the project. At present, we have collected plankton samples to be used for this project on California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises throughout southern California in the winter, spring, and summer. In winter 2015 CalCOFI began collecting tris-buffered 95% ethanol-preserved samples specifically for SBC BON from the port side paironet plankton net. CalCOFI will collect additional samples in fall. In spring of 2016, we will collect additional samples within the Santa

Barbara Channel in conjunction with the ongoing PnB survey conducted by UCSB. In addition, we have formed a collaboration with the Southern California Coastal Water Research Project (SCCWRP) who monitor biological and physical properties of near-shore waters off the coast of southern California. They have agreed to augment our monitoring by providing us with plankton samples that will be collected in winter 2016.

These samples will be sorted and identified (typically to species) based on morphotype by experts led by Co-Investigator Andrew Thompson at NOAA SWFSC, photographed, vouchered and tissue sampled for DNA barcoding of individual specimens. Once all fish eggs and larvae are identified, the specimens will be returned to the raw sample. Once morphological analysis is complete, the larvae will be returned to the raw plankton sample and species will be identified using metabarcoding techniques. Because most of the larval fishes in the SBC can be identified to species based on morphology, we will be able to directly assess the efficacy of metabarcoding to assess ichthyoplankton biodiversity.

We (Thompson, Miller) have leveraged SBC BON to acquire support for a new postdoc in year 2 that will work with Thompson on the ichthyoplankton barcoding project. The postdoc, Dovi Kacev, will be jointly funded by the Southern California Coastal Water Research Project Authority (SCCWRP) and NOAA SWFSC. SCCWRP is responsible for monitoring and assessing impacts of oceanic wastewater discharge in southern California and is deeply interested in new genetic techniques to monitor nekton.

C. Implement a tradeoff framework that optimizes allocation of sampling effort.

A major goal of the project is to compare the effectiveness of different methods of biodiversity sampling, exploring how the optimal mix of sampling depends on the goals of monitoring and the resources available. We will also consider how the optimal mix will change as technology improves (e.g., lower cost and better accuracy of genetic and computational methods). Much of this work will not begin until biodiversity data derived from a range of sampling methods can be assimilated and analyzed. However, we have started developing the modeling framework for these analyses, testing methods on simulated biodiversity datasets. Development of methods for analyzing tradeoffs will continue in year 2, and analysis of real data will begin as the data become available.

Data Management

Basic components of the SBC BON data storage and management system were established at the three research institutes at UCSB. Core data management systems are in place at the the Marine Science Institute, UCSB, and include data storage areas, email listservers, accounts and posix groups as needed, SVN

code repository, and protocols for usage of all systems. We installed a metadata database, based on that used by the Santa Barbara Coastal Long Term Ecological Research (SBC LTER) project and compatible with commonly used metadata specifications. SBC BON personnel are being trained in its use, and we expect datasets exports to begin in the middle of year 2. A website for the project was established (<http://sbc.marinebon.org>), and the domain made available to other marine BON partners. We developed SBC BON's IM system requirements and schedule, plus an inventory of datasets available for integration.

Data Manager O'Brien attended the 2015 annual meeting of the Earth Science Information Partners, in Monterey, CA, a forum which enables coordinated cyberinfrastructure across domain-specific communities, supported primarily by NASA and NOAA. We used this venue to a) identify additional data formats and practices already broadly used, and which are compatible with SBC BON's established practices and national and international data repositories and b) establish additional lines of communication with the IOOS community, e.g., CeNCOOS.

Outreach and education

SBC BON participated in a 2-day workshop this summer for sixth grade teachers that will be teaching the new ocean science curriculum starting this year. The Santa Barbara School district has chosen to focus their entire 6th grade science curriculum on ocean science, and the goal is to help to support the teachers in their understanding of some of the basic science content. They have chosen to use a curriculum called the Ocean Science Sequence (OSS) developed by the Lawrence Hall of Science (<http://www.erf.org/cerf2015>). There are 3 units in the curriculum that focus on 3 areas:

Ocean-Atmosphere Interactions
Flow of Carbon through land, ocean and atmosphere
Causes and Effects of Climate change

Miller presented an overview of the Biodiversity Observation Network concept and how it links to these areas of ocean science. Debora Iglesias-Rodriguez addressed climate change, its link to ocean acidification, and the range of possible effects on marine organisms.

In May 2015, Miller met with Channel Islands National Marine Sanctuary Education staff to discuss potential K12 audiences and outreach products that could be produced from SBC BON project. Two types of outreach were discussed; data interpretation and a technology piece focusing on detecting biodiversity trends over time. Next steps: CINMS education team will work with

the SBC BON project's image analysis group to learn more about outreach potential of the image recognition work and interactive maps being developed for this project and genomic tools being used to detect plankton and microbe biodiversity.

We (Emmett Duffy, Miller, Mueller-Karger) are organizing a session at the 2016 ASLO Aquatic Sciences meeting on Ocean Observing and Data Management, titled *MBON Voyage: Integrating marine biodiversity into ocean observing systems*.

Miller participated as an invited speaker in a session at the 2015 International Congress for Conservation Biology in Montpellier, France. The session, titled *Forging A Path From Space Observations To Action On The Ground: Satellite Remote Sensing For Conservation Applications*, was organized by Graeme Buchanan (Royal Society for the Protection of Birds) and Allison Leidner (NASA). Other project presentations are listed below.

Presentations:

Bell, T.W., K.C. Cavanaugh, D.A. Siegel, 2014: Remote Monitoring of Giant Kelp Photosynthetic Condition: An Evaluation of the Potential for the Hyperspectral Infrared Imager (HyspIRI) Mission. Poster presented at the 2014 AGU Fall Meeting, San Francisco CA, December 2014.

Miller, R.J., 2014: Demonstrating an effective Biodiversity Observation Network in the Santa Barbara Channel. Invited talk to the Channel Islands National Marine Sanctuary Advisory Board, Sept 2014.

Miller, R.J., 2014: Demonstrating an effective Biodiversity Observation Network in the Santa Barbara Channel. UCSB BON site visit, NASA & BOEM, Oct 2014.

Miller, R.J., 2014: Demonstrating an effective Biodiversity Observation Network in the Santa Barbara Channel. Invited talk to the National Marine Sanctuary Congressional Caucus, Nov 2014.

Miller, R.J., 2014: Developing a prototype Biodiversity Observation Network in the Santa Barbara Channel. Invited talk to the Southern CA Coastal Water Research Project, Dec 2014.

Miller, R.J., 2015: Demonstrating an effective Biodiversity Observation Network in the Santa Barbara Channel. 2015 NASA Carbon Cycle and Ecosystem Workshop, College Park, MD, April 21 2015.

Siegel, D.A., 2015: Ocean mixed layers and light availability for ocean photoprocesses. Seminar presented to the Oceanography Program, Jet Propulsion Laboratory, Pasadena CA, February 2015.

Siegel, D.A., 2015: Phytoplankton to the ocean's biological pump: How far have we come & how far do we have to go? Invited plenary talk. 2015 NASA Carbon Cycle and Ecosystem Workshop, College Park, MD, April 21 2015.

Bell, T.W., K.C. Cavanaugh and D.A. Siegel, 2015: Remote monitoring of giant kelp biomass and physiological condition: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI) mission. Poster presented at the International Ocean Color Research Meeting 2015, San Francisco, CA, June 2015.

Henderikx Freitas, F. and D.A. Siegel, 2015: Controls on phytoplankton and particle distributions in the Santa Barbara Channel, California. Poster presented at the International Ocean Color Research Meeting 2015, San Francisco, CA, June 2015.

Siegel, D.A., 2015: Hyperspectral remote sensing and applications to studies of the oceanic carbon pump. Oral presentation made at the International Ocean Color Research Meeting 2015, San Francisco, CA, June 2015.

Publications:

Bell, T.W., K.C. Cavanaugh, D.C. Reed and D.A. Siegel, 2015a: Geographic variability in the controls of biomass dynamics of giant kelp. *Journal of Biogeography*, in press.

Bell, T.W., K.C. Cavanaugh and D.A. Siegel, 2015b: Remote monitoring of giant kelp biomass and physiological condition: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI) mission. *Remote Sensing of the Environment*, in press.

Castorani, M.C.N., D.C. Reed, F. Alberto, T.W. Bell, R.D. Simons, K.C. Cavanaugh, D.A. Siegel, and P.T. Raimondi, 2015: Connectivity structures local population dynamics: a long-term empirical test in a large metapopulation system. *Ecology*, in press.

Johansson, M.L., F. Alberto, D.C. Reed, P.T. Raimondi, N.C. Coelho, M.A. Young, P.T. Drake, C.A. Edwards, K. Cavanaugh, J. Assis, L.B. Ladah, T.W. Bell, J.A. Coyer, D.A. Siegel, E.A. Serrão, 2015: Seascape drivers of *Macrocystis pyrifera* population genetic structure in the northeast Pacific. In review.

Koenigs, C., R.J. Miller, H.M. Page. Top predators rely on carbon derived from giant kelp (*Macrocystis pyrifera*). In Press, Marine Ecology Progress Series.

Miller, R.J., H.M. Page, D.C. Reed. Trophic versus structural effects of a marine foundation species, giant kelp (*Macrocystis pyrifera*). In Press, Oecologia.

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