COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE	☐ Special Exception to Deadline Date Policy	FOR NSF USE ONLY
NSF 15-596 03/04/16		NSF PROPOSAL NUMBER 1637632

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

DEB - Long-Term Ecological Research, (continued)

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
03/04/2016	1	08010000 DEB	1195	175104595	03/04/2016 12:00pm

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)
956006144		

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE: University of California-San Diego Scripps Inst of Oceanography

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE:
8602 La Jolla Shores Dr
Univ of California-San Diego
LA JOLLA, CA 92093-0210

AWARDEE ORGANIZATION CODE (IF KNOWN): 0013177010

NAME OF PRIMARY PLACE OF PERF: UCSD, Scripps Institution of Oceanography

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE:
UCSD, Scripps Institution of Oceanography

La Jolla ,CA ,920930210 ,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: CCE-LTER Phase III: Ecological Transitions in an Eastern Boundary Current Upwelling Ecosystem**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 6,762,000	72 months	08/01/16	

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)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☒ FUNDING MECHANISM Research - other than RAPID or EAGER
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☒ COLLABORATIVE STATUS A collaborative proposal from one organization (GPG II.D.4.a)

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Project Summary: **LTER: CCE Phase III: Ecological transitions in an Eastern Boundary Current Upwelling Ecosystem**

Overview: The *California Current Ecosystem* (CCE) LTER program addresses two over-arching questions: **What are the mechanisms leading to different ecosystem states in a coastal pelagic ecosystem? What is the interplay between changing ocean climate, community structure, and ecosystem dynamics?** The study region is the southern sector of the California Current System (CCS), a major upwelling biome where the 67-year CalCOFI program provides essential information characterizing both natural climate variability and progressive changes. The CCE site spans a biogeographic boundary region, hence is an early sentinel of climate change; shows low frequency variations that are correlated with much of the North Pacific; is the preferred spawning site for most of the epipelagic fish biomass in the CCS; exhibits a broad gradient of ocean conditions over a short geographic distance; encompasses a varved sedimentary record of the past two millennia; and has mature models. Previous, Phase II support of CCE led to extensive new findings: a new null hypothesis for abrupt ecosystem shifts, understanding of phenological changes in marine fish spawning, new roles for both Si-Fe interactions and mesopelagic fishes in mediating C export, long-term changes in nutrient stoichiometry in upwelling source waters, eddy-mediated transformations of plankton production, and alterations of mesopelagic fishes in relation to ocean de-oxygenation. CCE studies of mesoscale frontal systems found marked effects of ocean fronts on organisms across the food web ranging from bacteria to marine fishes. Glider-based studies showed elevated phytoplankton and zooplankton biomass at frontal discontinuities and satellite studies showed that such frontal features are increasing in the CCE region. Several thousand people were reached through outreach activities. This renewal proposal builds on our previous analyses of the mechanisms underlying abrupt changes in ecosystem state with three new program elements: (1) intensive analysis of *cross-shore transport* as a modulator of long-term ecosystem variation; (2) development of quantitative forecasts of the *biotic effects of El Niño-Southern Oscillation*; and (3) expansion of our ability to characterize ecosystem perturbations using *molecular approaches*. Multi-scale measurements of the five core LTER variables and their responses to secular ocean changes (warming, increased density stratification, de-oxygenation, and acidification) in the NE Pacific will be sustained.

Intellectual Merit: CCE-LTER studies are making excellent progress toward understanding ecological state changes and the development of a quantitative framework for forecasting future changes in ecosystem states in a major upwelling ecosystem. In Phase III we will conduct intensive shipboard Lagrangian process studies to test the role of *cross-shore transport* in exporting nutrients, other biogenic compounds, and organisms into the offshore zone, thereby modifying population dynamics and biogeochemical export. Climate sensitivity of cross-shore transport will be assessed using autonomous measurements and integrative modeling. Other mechanisms related to ecosystem transitions (*in situ changes in stratification, alongshore advection, top down predation*) will be analyzed, respectively, by field studies employing a space-for-time exchange, in situ and remote sensing measurements combined with modeling, and bioenergetic modeling. Collaborative studies will develop a new framework for forecasting ENSO effects on marine pelagic ecosystems along the U.S. west coast. Molecular approaches will be used to characterize trends in microbial diversity and associated plankton interactomes.

Broader Impacts: This program will develop a new quantitative basis for forecasting the effects of climate perturbations on the management of key living marine resources, including numerous fishes, invertebrates, marine mammals, and seabirds. The study region also affects CO_2 exchange and carbon sequestration, as well as human recreation, navigation, and the livelihoods of large numbers of U.S. residents. The site encompasses a National Marine Sanctuary and constitutes major spawning habitat for most of the epipelagic fish biomass in the CCS. This research will involve extensive training of graduate students, undergraduate REU's, and will create teacher opportunities. Public programs and outreach efforts will be expanded in collaboration with the Birch Aquarium at Scripps, to increase public awareness and understanding of climate effects on coastal pelagic communities, to connect the public directly to the process of ocean research, and to expand the pipeline of careers in the ocean sciences.

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Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1. Results from Prior LTER Support- Ecological Transitions in the California Current Ecosystem: ***CCE-LTER Phase II***, OCE-10-26607, $5,640,000 + supplements, Aug. 2010 - July 2016

The California Current Ecosystem (CCE) Long-Term Ecological Research site was initiated in August 2004 (Phase I) with the goal of understanding the mechanisms underlying ecosystem state changes in a coastal upwelling ecosystem. Our over-arching questions are: **What are the mechanisms leading to different ecosystem states in a coastal pelagic ecosystem? What is the interplay between changing ocean climate, community structure, and ecosystem dynamics?** These remained our primary motivating questions in Phase II (ending in 2016), as well as for the present renewal proposal (Phase III). CCE is complemented by the CalCOFI (*California Cooperative Oceanic Fisheries Investigations*) program, which provides context for our studies and a 67-year time series of changing ecosystem properties on multiple time and space scales. As a part of our focus on ecological state changes, we pay close attention to the major modes of climate variability in the North Pacific (ENSO, NPGO, and PDO) and secular changes in ocean conditions (e.g., ocean warming, stratification, acidification, and de-oxygenation). The exceptional Pacific warm anomalies of 2014-15 (Bond et al. 2015, Hartmann 2015) and the present major El Niño of 2015-16 are also areas of active interest in CCE.

Here, we first report selected results from CCE Phase II, including progress enabled by supplemental funding. This is followed by the Phase III Proposed Research section, a description of Related Research Projects, and Education, Outreach, and Capacity Building (EOCB) for Phase III. (For immediate description of our new research, proceed directly to p. 13.) Supplementary documents below describe our Data Management, Project Management, and Postdoctoral Mentoring plans. In Phase II, CCE has produced 222 publications (182 journal articles, 14 book chapters, 6 conference proceedings and reports, 19 PhD theses, and 1 prologue to a popular book; see the ccelter website for a complete listing).

Ten most significant publications resulting from the last 6 years of funding

Ecosystem state changes - The theme of ecological transitions is central to CCE. Two Phase II papers in particular pertain to theoretical principles of ecosystem state changes, their underlying mechanistic control, and statistical methods for detection.

1. Double integration hypothesis. Di Lorenzo and Ohman (2013, *PNAS*) utilized a six-decade record of zooplankton to create a null hypothesis for the mechanisms leading to abrupt changes in the California Current ecosystem, as illustrated by key euphausiid species (Fig. 1A) and other ecosystem variables (Fig. 1B). A simple autoregressive 1 model explained abrupt changes in ecosystem state, without invoking nonlinear threshold models with hysteresis (Scheffer et al. 2009). The oceanic response to white noise variability in the atmosphere "reddens" the variance spectrum; the biotic response to oceanic variability further accentuates low-frequency variation, resulting in a "super-reddened" variance spectrum. Occasional abrupt changes occur as a natural consequence of this super-reddened spectrum. This result implies that, while biotic populations in the CCE region are strongly influenced by physical variables, it is not necessary to invoke nonlinear "regime shifts" that have been previously assumed.

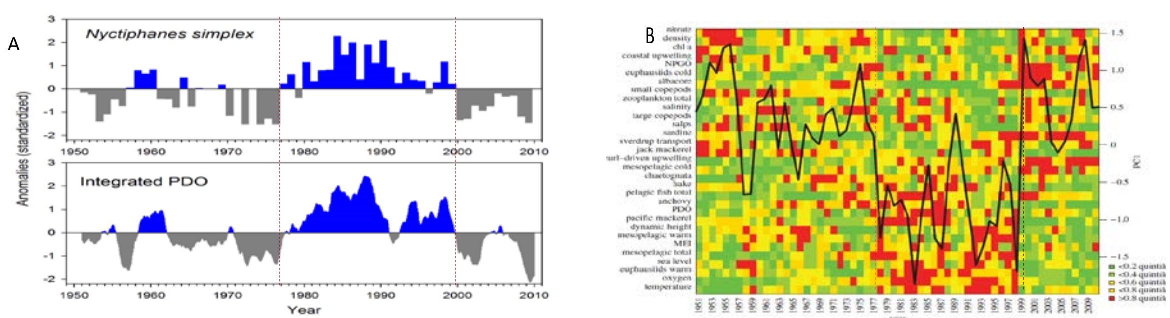

Fig 1. **Abrupt ecosystem transitions** in (A) (upper) the euphausiid *N. simplex* and (lower) an AR1 integration of the Pacific Decadal Oscillation (cf. Di Lorenzo and Ohman 2013), and (B) a suite of physical and biological properties in the CCE region (Lindegren et al. 2016). Dashed red lines indicate major transitions.

2. Abrupt transitions and linear tracking of the physical environment. In a related paper, **Bestelmeyer et al.** (2011, *Ecosphere*) compared relatively abrupt ecosystem changes across four different LTER sites: CCE (subtropical krill), Jornada desert (grasslands to shrublands), Santa Barbara coastal (sea cucumbers), and Palmer (Antarctic to sub-Antarctic penguins). This paper tests for alternate drivers during different ecosystem states, addresses numerical methods used to diagnose abrupt transitions, and evaluates the prospects for early detection of abrupt ecosystem changes. Results from CCE showed that rapid changes in ecosystem state closely tracked the Pacific Decadal Oscillation (PDO), but with no change in the functional relationship between krill and the PDO across a broad range of ocean variation. This study found no evidence for feedback mechanisms that maintain ecosystem conditions in a "preferred state" or "regime." CCE's results provide an important contrast to other LTER sites.

***Phenology* – 3. Changing phenology of fish spawning.** Then-graduate student Rebecca Asch (Asch 2015, *PNAS*) utilized 6 decades of CalCOFI ichthyoplankton data to infer phenological changes in fish spawning. Of 43 species analyzed, 39% of the fishes showed progressively earlier timing of spawning (Fig. 2), while 18% were delayed. The species with advanced phenology were typically those with an offshore, pelagic distribution, while delayed species were associated with coastal, demersal habitats. These changes were linked to long-term changes in timing of surface water warming. Phenological advances occurred at a mean rate of 6.4 days decade^{-1}, which is considerably faster than rates for most terrestrial ecosystems, but comparable to rates from other marine ecosystems. Asch's projections based on IPCC scenarios suggest that these phenological trends will continue unabated in the CCE.

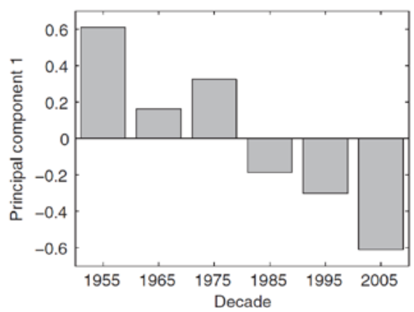

Fig. 2. Changes in phenology of fish spawning. First principal component of the central tendency of seasonal occurrence of larval fishes. Positive values of PC1 indicate later occurrence of larvae, negative values earlier occurrence. Mean rate of change is an advance of 6.7 days decade^{-1}. Asch (2015).

Changing ocean biogeochemistry - Several CCE participants addressed biogeochemical cycles and their relationship to climate forcing. CCE graduate students expanded our analyses to encompass nearly all major variables needed to quantify biogeochemical budgets for the ocean water column.

4. Carbon export budget for CCE. Led by then-graduate student Michael Stukel, **Stukel et al.** (2011, *Limnol. Oceanogr.*) used a trophic model and measurements made during CCE Lagrangian process cruises to characterize export production and probe the relationship between new production and export production in sub-regions of the CCE domain. Rates of new and export production (^{234}Th deficiencies) were strongly decoupled spatially, likely due to the offshore transport of upwelled water and associated communities (see Fig. 10, p. 15). Calculated rates of fecal pellet export were similar to rates of carbon export inferred from ^{234}Th. These results suggest that unmeasured processes (e.g., direct sinking of unconsumed phytoplankton) were negligible in this environment. The overall conclusion is that zooplankton are the primary driver of vertical carbon flux in this system and that cross-shore fluxes are a key process in the CCE region. This study influenced our presently proposed directions for CCE Phase III.

5. Contributions of mesopelagic fishes to active carbon transport. Peter Davison's dissertation research illustrated dramatic undersampling of mesopelagic fishes in CCE and nearby waters in previous studies, and the previously unrecognized role of mesopelagic fishes in active carbon transport into the mesopelagic zone. **Davison et al.** (2013, *Progr. Oceanogr.*), a collaboration between CCE and NOAA's Southwest Fisheries Science Center, combined trawl and acoustic estimates of mesopelagic fish abundance at stations from Baja California (30°N) to British Columbia (48°N) with a metabolic model used to estimate vertical carbon exchange. Fish-mediated export (FME) of organic carbon was estimated to account for 15 to 17% of the total organic carbon exported in the CCE area. FME was even higher in oligotrophic regions, approaching a remarkable 40% of the total. These results strongly suggest that FME needs to be considered in carbon budgets not only for the CCE, but for all ocean regions beyond the continental shelf.

6. Si-Fe interactions. In a collaborative study involving several CCE participants and Santa Barbara Coastal LTER scientists Mark Brzezinski and Jeffrey Krause, **Brzezinski et al.** (2015, *J. Geophys. Res. Oceans*) illustrated how iron limitation impacts diatom-mediated carbon export in the California Current System via silica ballasting. Iron-depleted phytoplankton take up Si in excess of nitrate and carbon, thereby increasing their sinking velocities. This study represents the first published documentation of this phenomenon in situ and shows how CCE's Lagrangian approach can address fundamental interactions between iron limitation and the cycling of silica and carbon in upwelling systems. The results have implications not just for our region, but also for global-scale interconnections between iron, silica, and carbon cycling in high-nutrient, low-chlorophyll regimes. In CCE, enhanced contributions of iron-limited, silica-ballasted diatoms to export appears to be associated with fronts (Stukel et al. in review).

Eddy-related food web transformations - This modeling study helps set the stage for our Phase III focus on cross-shore transport processes and their sensitivity to climate forcing.

7. Biological transformations in a cyclonic eddy. Postdoc Fanny Chenillat led a study analyzing the importance of cyclonic eddies for biological production and transport in the CCE region. Although mesoscale eddies are well-known features of the CCS, their influence on the pelagic ecosystem remain poorly quantified. **Chenillat et al.** (2015, *J. Geophys. Res. Oceans*) used a coupled physical-biological model combined with Lagrangian particle tracking to show that the uplifted pycnoclines characteristic of cyclonic eddies enhance nitrate flux, stimulating planktonic production in the eddy core. This production is highest in waters below the surface mixed layer and above the base of the euphotic zone – a region invisible to satellite remote sensing. The eddies remain coherent for up to a year, transporting nutrient-rich coastal waters offshore in the eddy core. Cyclonic eddies subsequently become localized regions of significantly enhanced planktonic production in otherwise oligotrophic offshore waters of the CCE.

Three synthetic works - CCE published two special issues, one devoted to time series research since the advent of CCE (*Deep-Sea Research II*, Goericke and Ohman 2015, eds.), the other to processes at the first of our major ocean frontal studies (A-Front, *Journal of Plankton Research*, Landry, Ohman et al. 2012). CCE contributed 3 papers to an issue of *Oceanography* (Sept. 2013) devoted to the marine LTER sites.

8. CCE time series research, special issue of *Deep-Sea Research II* (v. 112, 2015). "*CCE-LTER: Responses of the California Current Ecosystem to Climate Forcing*" focused on long-term measurements of hydrographic and biological variables in the CCE and the interpretation of the time series via models. The articles are based on the 6 decade long CalCOFI data set or other CCE time series studies, some integrated with modeling. Notable results include: dramatic changes of N:P and Si:N ratios in the source waters for upwelling in the CCE, thought to be driven by changing characteristics of waters advecting into the CCE; a glider-based study of frontal areas that were often, but not always, zones of enhanced phytoplankton and zooplankton biomass; the importance of coastally trapped waves in dominating interannual Sea Surface Height variability, in contrast to wind stress curl explaining alongshore currents; and the co-variability of a 25-year long CCE seabird time series with climate variables, offshore mesopelagic and nearshore fishes, and krill abundance.

9. A-Front special issue, *Journal of Plankton Research* (v. 34(9), 2012). Eight papers published as the "A-Front Study" document abrupt shifts in pelagic community composition and biomass, from bacteria to fish, across a sharp north-south frontal system overlying deep waters (3700 m). This front separated cooler mesotrophic waters of coastal upwelling origin from warm oligotrophic waters. Compared to adjacent waters, the frontal interface was a site of highly enriched large diatoms, enhanced bacterial production and phytoplankton photosynthetic potential, elevated concentrations of suspension-feeding zooplankton and copepod nauplii, and high acoustically-estimated epipelagic fish. Thorpe-scale analysis indicated increased nitrate fluxes into the euphotic zone at the front. A retrospective satellite study demonstrated multi-decadal increasing trends in ocean fronts in the CCE region, suggesting these features will become increasingly important in the future California Current Ecosystem.

10. CCE-LTER overview, *Oceanography* (v. 26(3), 2013). CCE contributed three articles to a special issue highlighting contributions of the eight coastal marine sites in the US LTER network. CCE's contributions present the ecological framework that underpins research at the CCE site; illustrate how numerical models are used to synthesize large, complex data sets and describe how atmospheric, physical oceanographic, and biological variables combine to create long-term dynamical fluctuations in the California Current ecosystem; and provide examples of CCE's integration of autonomous instrumentation (gliders, profiling floats, surface drifters, enhanced moorings, and satellite remote sensing) with shipboard-based observations to describe the ecosystem structuring role of "event-scale" phenomena.

Other notable results from CCE include tests of different aspects of the Metabolic Theory of Ecology (Chen et al. 2012, Taniguchi et al., 2014). Other studies analyzed effects of declining dissolved oxygen on mesopelagic fishes (Koslow et al. 2011, Netburn and Koslow 2015), recorded C fluxes to the abyssal sea floor associated with a salp outbreak (Smith et al. 2014), contributed to 10 chapters of the EcoTrends volume (Peters et al. 2012), used a Trait-based approach to predict copepod diel vertical migration from satellites (Ohman and Romagnan 2016), analyzed microbial remineralization and photochemistry as controls on seawater iron chemistry (Bundy et al. 2016), and others. A CCE graduate student demonstrated a 100-fold increase in plastic micro-debris in the North Pacific in the past 40 years (Goldstein et al. 2012). CCE's Phase II focus on **mesoscale frontal systems** led to a series of important new insights, as briefly summarized below.

Results from Phase II Frontal Studies

CCE scientists conducted intensive studies of three frontal systems, designated the A-Front (field work completed near end of Phase I, analyses completed and papers published during CCE Phase II), C-Front, and E-Front, as well as contrasting non-frontal conditions of August 2014 when the NE Pacific was anomalously warm and exhibited weak frontal gradients. In addition, we carried out a 5-year study of biophysical fronts using *Spray* ocean gliders as well as an analysis of changing frontal occurrence over ~2 decades using satellite remote sensing. We further used physical and coupled biophysical models to analyze the mechanisms of frontal influences on CCE plankton dynamics.

Although frontal gradients and frontal dynamics varied, we documented enhanced phytoplankton (Taylor et al. 2012, Landry et al. 2012, de Verneil and Franks 2015, Powell and Ohman 2015a), mesozooplankton (Ohman et al. 2012, Powell and Ohman 2015a) and fish biomass (Lara-Lopez et al. 2012) at deep-water frontal features, i.e., not associated with shelf-breaks or tides. We found that frontal systems can disproportionately influence nutrient fluxes (Li et al. 2012), bacterial production (Samo et al. 2012), phytoplankton production (Li et al 2012, Taylor et al. 2012), and mesozooplankton recruitment and density of organic aggregates (Ohman et al. 2012). We also found that frontal systems can markedly influence the spatial distributions of diverse types of organisms, including cyanobacteria and diatoms (Taylor et al. 2012), mesozooplankton (Ohman et al. 2012, Powell and Ohman 2015b), and the vertically migratory component of the mesopelagic fish assemblage (Lara-Lopez et al. 2012, Netburn 2016). An approach that mapped streamlines by fitting geostrophic currents to *in situ* ADCP and density fields showed that Chl-*a* decreased as it advected along the southward-flowing axis of E-front (de Verneil and Franks 2015). At both the C-Front and E-Front, diatoms contributed disproportionately to primary production, biogenic Si production, and export fluxes (Krause et al. 2015, Brzezinski et al. 2015). Stukel et al. (in review) illustrate elevated carbon export (by ~ 2X) in frontal zones, driven by high mesozooplankton fecal pellet production and increased mineral ballasting by Fe-stressed diatoms. Another E-Front study illustrated that cross-frontal shoaling of the aragonite saturation horizon is accompanied by vertical habitat compression and enhanced shell dissolution of thecosome pteropods

(Bednaršek and Ohman 2015). Notably, satellite analyses demonstrated progressive increases in frontal frequency (Kahru et al. 2012), suggesting that these discontinuities may increasingly structure the CCE pelagic ecosystem and contribute to its propensity for abrupt ecosystem shifts.

Broader Impacts, and Results from Supplemental Support

Supplemental **Schoolyard** support has enabled us to engage several thousand people in CCE-related activities and experiences (e.g., Fig. 3). CCE's formal partnership with the Birch Aquarium at Scripps (BAS) markedly increased our connection to broader audiences. These activities included *Pier Walks*, involving over 1,000 participants with collection and examination of plankton samples with a CCE researcher and educator; *Think Tank: Plankton*, an interactive experience for guests (N=2,250) of all ages to learn about adaptations that help plankton survive; an annual Teacher Open House; *Explore It Plankton Activities; Exploring Ocean STEM Careers;* SEA (*Science, Exploration, and Adventure)* Days, and others. A *Teacher Professional Development* workshop will be held in Spring 2016, engaging educators in the use of authentic CCE data in the classroom. Other activities included presentations in elementary schools, middle schools, 5 high schools including the Preuss School Science Club serving 1st generation college-bound students, *Institute of the Americas Science and Innovation Summer Camp* (2011 & 2012), and *Expanding Your Horizons*, a local organization targeting girls in science (2011-2015).

Fig. 3. CCE Education, Outreach and Capacity Building events at the Birch Aquarium at Scripps, at sea on the Ocean Institute's Sea Explorer, in the SIO Pelagic Invertebrates Collection, on the Scripps pier, and elsewhere at UCSD. The two photos in the upper right are of Teachers-at-Sea: Ms. Carmina Ramirez with 2 REU students, 1 other undergraduate, 2 post-docs, and a graduate student; and Ms. Dana Lebental holding her first salp (pelagic tunicate).

Our other EOCB partner, *The Ocean Institute* (OI), is a non-profit educational institute located in Dana Point, CA. Several times a week OI takes schoolchildren to sea for 2-hour field experiences in conjunction with a 2-hour lab. Partnership with CCE led to the development of post-visit materials and an optional in-class project. This collaboration also led to our joint *Chlorophyll-Temperature Time Series*, initiated by CCE in 2006 and now an integral part of OI's *Earth's Changing Climate* and *Human Impacts on Coastal Ecosystems* programs, which have served over 9,100 students since they were piloted in 2013 and 2014, respectively. The Chl-*a*-Temp time-series project directly involves OI student visitors in the collection of seawater samples for analysis by fluorometry and illustrates basic principles of coupling between physical and biological processes in the coastal ocean. CCE has also developed a variety of resources specifically targeting teachers and students. CCE data are publicly accessible via DataZoo, and our partner programs post data for the public interest and use, including data from *Spray* gliders, CCE moorings, satellite remote sensing, and CalCOFI.

Our **REU** (Research Experience for Undergraduates) program supported 26 undergraduates, 81% of whom were women or from underrepresented groups, in summer research. Of our REU participants, 10 have applied to or intend to apply to graduate school.

Our **RET** (Research Experience for Teachers) program supported 8 teachers in Phase II, including 3 who participated in intensive, month-long at-sea experiences that they considered highly positive for them and for their teaching. Our teachers-at-sea included a representative from a primarily African-American school district in Compton, CA and from a predominately Hispanic school district in Calexico, CA. Ms. Carmina Ramirez wrote an at-sea blog in both English and Spanish, the latter subsequently reprinted in La Opinión, the largest Spanish language newspaper in the U.S. She published an article about her experiences in *California Educator,* a magazine of the California Teachers Association (circulation >325,000; Ramirez 2015), and another for the LTER Network News (30 Dec. 2014). Ms. Ramirez directly incorporated her field science experience into her lesson plans, both for her own classroom serving 9th grade science students from the border school district of Calexico and for a national audience. Other teachers also developed lesson plans on ocean warming and increased stratification, nutrient cycling, plastic microdebris, and ocean acidification.

Incorporation of CCE data, samples, and findings into classroom teaching includes contributions to 3 undergraduate classes at UCSD and 7 graduate classes at SIO. Our involvement in media presentations depends on issues of the day. The last two years have seen great public interest in major Pacific Ocean warming anomalies (a.k.a., "the Blob," e.g., Bond et al. (2015)), in beach strandings of subtropical plankton such as pelagic red crabs, and in the major El Niño of 2015-16. CCE personnel have given numerous interviews with local (San Diego Union-Tribune and KPBS public radio) and national (Reuters, Weather Channel, Science Fridays, etc.) media outlets to better educate the public on these phenomena. Lead PI M. Ohman wrote a prologue for a new public audience book entitled *Plankton: Wonders of the Drifting World* (2015. Christian Sardet, author), which has been widely disseminated. We have created a public interest pictorial web guide to the *Zooplankton of the San Diego Region*. Zhang et al. (2012) analyzed the perspectives of local San Diego fishers on climate change. Two CCE graduates have gone on to Knauss fellowships in D.C., working in the legislative and executive branches, respectively.

The CCE EOCB program involves many graduate students, post-doctoral scholars, scientists, educators, undergraduates, and volunteers, as illustrated below for our Phase II funding.

Category	Grad. Students	Post-docs	Under-grad REU	Under-grad Other	Technical Staff	Cruise Volunteers	High School courses	RET Teachers	Under-grad Courses	Grad Courses
SIO/UCSD	44	13	19	11	27	27	5	0	3	7
Other Institutions	6	4	7	2	9	18	0	8	0	0
Total	50	17	26	13	36	45	5	8	3	7

Our **Cross-site activities**, in addition to Bestelmeyer et al. (2011), Brzezinski et al. (2015), and Krause et al. (2015) mentioned above, include serving on the Editorial Board of the Ecotrends project and co-publishing 10 chapters of that book with other LTER sites (Peters et al. 2013). A CCE graduate (M. Stukel) became a postdoc at PAL. CCE and PAL share an information manager. CCE, SBC, and MCR graduate students and postdocs meet for an annual exchange, and the same 3 sites jointly supported a graduate student in modeling activities under A. Miller's (CCE) guidance. CCE, SBC, and other graduate students recently created a blog entitled "*Short Stories about Long-Term Research*." M. Ohman served a

3-year term on the LTER Executive Board, on the program committee for the LTER mini-symposia (2012, 2014), and participates actively in many LTER activities. Other CCE personnel serve or have served on the Climate Committee, Information Management Executive Committee, IM working groups and tiger teams, Science Communications Workshops, Higher Education conference calls, and others. CCE has participated in (and led or co-led) many working groups at the last two LTER All-Scientists Meetings, as well as many Science Council activities.

Information Management. Supplemental support allowed us to redevelop the CCE project website using Drupal content management system (CMS) as the website platform. Other supplemental funds supported purchase of a new server, completing our transition to a fully Linux-based server arrangement. CCE data have been accessed extensively by people in 29 countries around the world (Fig. 4). Supplements supported two contract employees jointly by CCE and PAL to improve data access and availability. We added additional databases including a comprehensive database to support an integrated environment for producing research-critical data products and improved QA/QC. We re-designed our on-disk file structure, standardized data processing scripts and a tracking database, providing a well-documented, traceable workflow for data submission, processing and publishing.

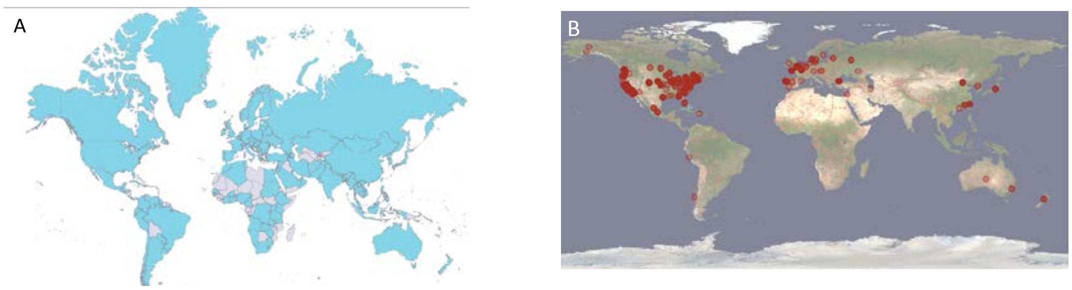

Fig. 4. (A) Access of the CCE-LTER website by country of IP address (light blue indicates CCE website access). (B) Downloads and views of CCE data by location of IP address (intensity of shading proportional to usage).

Permanent Equipment funds have been invaluable to CCE in purchasing common-use equipment, upgrading obsolete instruments, and replacing one item lost at sea after a cable failure. Purchases include a trace metal-clean coated cable and block, RAID array storage, an enhanced DIONEX detector for stable N,C isotope analysis, -80º C freezer, fluorometer, Acousonde probe, SeapHOx and SUNA sensors for CCE moorings, scanning uv-vis spectrophotometer, strobed LED for MOCNESS, a Laser Optical Particle Counter, airfuge for isolating viruses, and drifters for our Lagrangian field studies. This support has contributed to graduate student research and training and to many publications.

Ocean Acidification. T. Martz' lab constructed a custom underway flow through pCO_2/pH/Temp/Salinity system capable of measuring, logging, and transmitting data in real time. The system integrates three commercial systems (Sunburst SuperCO_2; Honeywell UDA2182; Sea-Bird 37) into a common data hub (a PC with LabView). It was deployed on the last four CCE-augmented CalCOFI cruises. We are developing real-time QC algorithms and enhancing the LabView user interface. We purchased a LI-COR Model 7000 NDIR CO_2 analyzer that is being used by the A. Dickson lab to construct an infrared-based system for measuring total DIC. The instrument will be used for faster, hence cheaper, analysis of seawater samples from CCE and CalCOFI, to document changing CO_2 conditions.

RAPID El Niño Response Cruise – A group of CCE scientists will be conducting an intensive process-oriented study (spring 2016) of the impact of the present El Niño on key pelagic ecosystem rate processes.

2. Proposed Research

Brief Historical Development of CCE, Conceptual Framework, & New Directions for Phase III

The California Current Ecosystem (CCE) LTER site is a coastal upwelling biome forced by physical processes on multiple time and space scales. The southern sector of the California Current region is an ideal location for an LTER site because it: is the location of the 67-year (ongoing) CalCOFI ocean time series; includes a biogeographic boundary region that serves as an early sentinel of climate change; is representative of the productive pelagic coastal upwelling biomes found along the eastern boundaries of all major ocean basins; is the preferred spawning site for ~90% of epipelagic fish biomass in the California Current System, as well as many invertebrates and nearshore fishes; encompasses the varved sedimentary (paleoceanographic) record of the Santa Barbara Basin; shows low-frequency changes that are correlated with changes in much of the NE Pacific; has mature models; and exhibits a large gradient of ocean conditions over a small geographic distance, encompassing much of the range of productivity and hydrographic structure found in the world ocean.

In CCE **Phase I** (2004-2010), our early conceptual view, based on our initial results, was that abrupt changes in ecosystem state are explained by nonlinear responses of pelagic populations to linear changes in the physical environment (e.g., Hsieh et al. 2005). While small, progressive changes in the physical environment are known to be able to lead to abrupt transitions in ecosystem state (e.g., Scheffer et al. 2009), there is considerable debate as to whether such changes are quickly reversible or maintained in specific states by feedback mechanisms that inhibit reversibility (but see Petraitis 2013). A related issue is whether pelagic ecosystems exhibit a small number of resilient states or 'regimes' (e.g., Moellmann et al. 2015) or, alternatively, exhibit continuous underlying variability but no preferred states (e.g., Rudnick and Davis 2003). Our earlier view favored the perspective of preferred states, although this was refined in Phase II. Phase I also introduced our *space-for-time* exchange process studies (Rykaczewski and Checkley 2008, King and Barbeau 2007, Hopkinson and Barbeau 2008, Landry et al. 2009, and others). Other studies documented long-term changes in the physical and chemical environment (Kim and Miller 2007, Chhak and DiLorenzo 2007, Bograd et al. 2008, 2009) and biotic responses (DiLorenzo et al. 2008, Lavaniegos and Ohman 2007, Smith et al. 2008, Kahru et al. 2009). We also developed or parameterized allometric, coupled biophysical ROMS, and other models.

In CCE **Phase II** (2010-2016), our role in an important synthetic cross-LTER paper (Bestelmeyer et al., 2011, described above) revealed a lack of evidence for preferred ecosystem modes or 'regimes,' in contrast to those observed at some other LTER sites. We found that the best conceptual model describing abrupt changes in our system over time is not a nonlinear model with hysteresis (Fig. 5, Model III, Scheffer et al. 2009), as commonly assumed for marine ecosystems, but strong linear coupling of biological processes to low-frequency climate forcing (e.g., Bestelmeyer et al. 2011, Di Lorenzo and Ohman 2013), possibly with threshold effects (Fig. 5, either Model I or Model II). These results have led us to conclude that our ecosystem changes are generally reversible, or have been until very recently. Phase II introduced our focus on the ecological disturbance regimes associated with **mesoscale fronts,** described above. In Phase II we continued to document biotic responses to long-term changes (e.g., Bograd et al. 2015, Netburn and Koslow 2015, Goericke and Ohman 2015 (eds)). Modeling developments included continuum size-structured models (Fuchs and Franks 2010, Poulin and Franks 2010, Taniguchi et al. 2014), 'Darwin' models (Goebel et al. 2013, 2014), and coupled biophysical models that have been closely integrated with our field measurements (e.g., Stukel et al. in review).

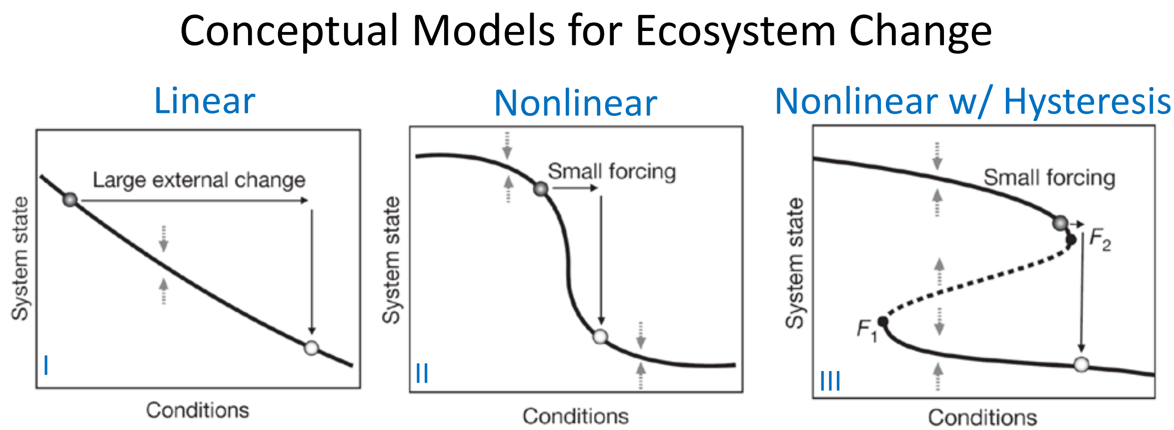

Fig. 5. Conceptual models for trajectories of ecosystem change, from Scheffer et al. 2009. Model I (Linear), Model II (Nonlinear with threshold), Model III (Nonlinear with thresholds and hysteresis).

This **Phase III** renewal proposal retains a focus on the **mechanisms underlying ecosystem transitions**, or ecological state changes, in our coastal pelagic upwelling ecosystem. Such changes are exemplified by the relatively abrupt changes documented in the CCE region in Fig. 1. As we focus on improving our mechanistic understanding of these ecosystem transitions, we also recognize the interactions of multiple time-scale climate drivers in altering the CCE pelagic ecosystem. These drivers include *progressive long-term trends* (including ocean warming, increased stratification, ocean acidification, and de-oxygenation), *decadal-scale variations* of a quasi-periodic nature (e.g., NPGO and PDO), and *interannual variations* (dominated by ENSO). We also seek to characterize and understand these multiple drivers, and interactive effects, in altering the pelagic ecosystem of CCE. Our ultimate goal is to develop a quantitative framework for forecasting future changes in ecosystem states.

The overarching questions we will address in the CCE program remain:

What are the mechanisms leading to different ecosystem states in a coastal pelagic ecosystem? What is the interplay between changing ocean climate, community structure and ecosystem dynamics?

We have identified four principal mechanisms that could lead to the observed ecosystem shifts in the California Current pelagic ecosystem:

- **Sustained, anomalous alongshore advection of different assemblages** -- Temporal variations in north-south transport introduce organisms of different geographic origins into the southern sector of the California Current Ecosystem.
- **In situ food web changes in response to altered stratification and nutrient supply --** Changes in the species structure, trophic connections, and pathways of energy flow occur in response to changes in water column vertical stratification. Stratification modifies the rate of supply of limiting nutrients (macronutrients or trace metals) for phytoplankton production. Altered nutrient supply leads to altered rates of primary production and/or compositional changes in the phytoplankton, which propagate through the food web.
- **Changes in cross-shore transport and loss/retention of organisms** -- Temporal changes in the rates of cross-shore transport, via mean flow, coastal filaments, or propagation of mesoscale eddies, modify the probability of retention of nutrients and organisms in the nearshore coastal zone.

- **Altered predation pressure** -- Altered abundances (or dietary shifts) of planktivores lead to selective mortality and altered abundances and composition of the planktonic food web.

Our Conceptual Framework for CCE studies is illustrated in Fig. 6. This figure depicts both spatial differences in ecosystem structure across the CCE region, and also encapsulates the four primary mechanisms underlying ecosystem temporal change that form the focus of CCE science (described above). The CCE Conceptual Framework should be considered in combination with the models underlying ecosystem change in Fig. 5.

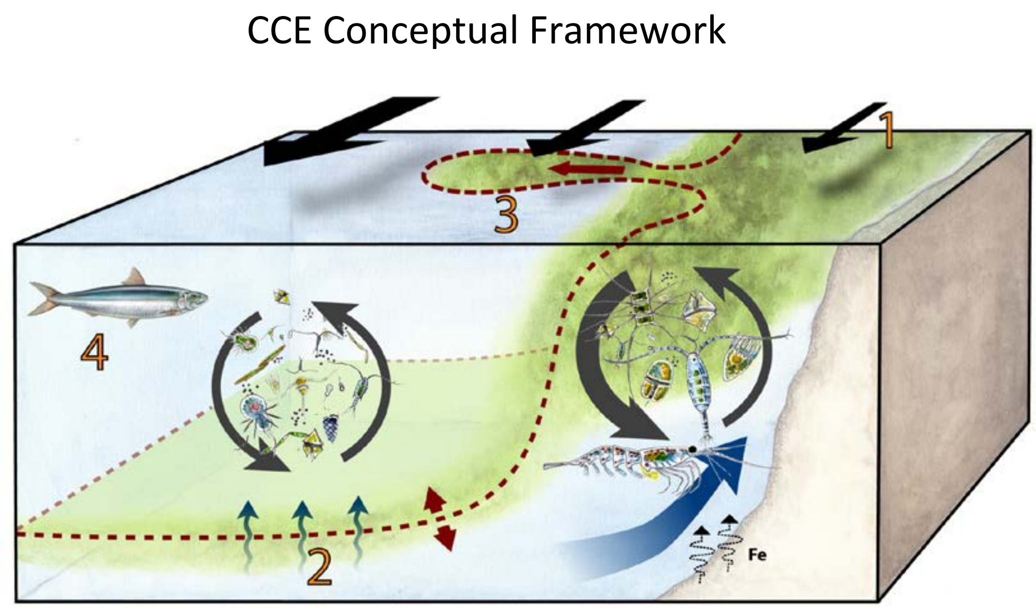

Fig. 6. Conceptual Framework illustrating the hypothesized mechanisms leading to ecosystem transitions in the CCE region. **1. Alongshore transport, 2. Altered stratification and nutrient supply, 3. Cross-shore transport, 4. Predation**. The diagram also illustrates spatial variations in CCE food webs associated with strong coastal boundary upwelling (large blue arrow) and weaker wind stress curl upwelling offshore (small blue arrows). (Mike Landry and Kirsten Carlson)

We will continue to evaluate each of these mechanisms in the next six years of our LTER site, although the approaches taken differ among the four mechanisms considered, as described further below. **Anomalous advection** will be addressed by calculation of volume transports from moorings, gliders, satellite altimetry, and shipboard hydrography. **In situ food web** changes will be analyzed on our experimental process cruises using a *space-for-time exchange* (i.e., the hypothesis that spatial variability in the CCE region can be used as an analog for change in one subregion over time). **Changes in cross-shore transport and loss/retention of organisms** will be analyzed in detail on our Lagrangian design process cruises, complemented by autonomous measurements via ocean gliders, moorings, coastal radar, and satellite remote sensing. Changes in **predation pressure** will be tested using compendia of predator and prey trophic linkages, biomass, and bioenergetic models. We recognize that these four mechanisms are not mutually exclusive.

We propose three major new or expanded directions for CCE Phase III research: **(1)** An intensive focus on *cross-shore transport processes*, and their climate sensitivities, as modulators of long-term ecosystem variation in the CCE region. Based on our work in Phase II, combined with other results suggesting that long-term changes will occur in upwelling favorable winds in some sectors of the California Current System and most other eastern boundary currents (Wang et al. 2015, Sydeman et al. 2015, Rykzaczewski et al. 2015), we anticipate changes in wind stress will lead to future changes in cross-shore fluxes of nutrients, biogeochemically relevant elements, and organisms via mesoscale features. The principal features of interest are coherent cross-shore flow structures such as filaments and eddies (Keister et al. 2009a,b, Davis and Di Lorenzo 2015a). **(2)** Development of a quantitative basis for forecasting the *biotic effects of ENSO*. Because ENSO is the dominant component of our ecological disturbance regime, we will analyze ecosystem responses to the major El Niño of 2015-2016 and the interaction of the present El Niño with the preconditioning effects of the "Blob" anomalies of 2014/15 (Bond et al. 2015, Hartmann 2015) and long-term, progressive ocean warming. Complementing our intensive observational and experimental studies of El Niño, we are leading a new effort to develop biophysical models directed toward forecasts of the biotic effects of ENSO for the CCE region and much of the U.S. west coast. **(3)** Expansion of our ability to measure responses to ecosystem perturbations using *molecular tools* to characterize prokaryotic and eukaryotic diversity, in addition to other approaches.

In Phase III we will continue to measure the core variables central to all LTER sites: disturbance regimes, inorganic nutrients, primary production, organic matter, and population studies. These core measurements are closely integrated into our studies of mechanisms underlying ecosystem changes. The CCE site addresses the core variable measurements and explicit hypothesis tests using five interrelated program elements: Experimental Process Cruises; Time-series Observations; Modeling; Information Management; and Education, Outreach, and Capacity Building.

We now briefly describe the physical and biotic context for CCE, followed by a more detailed description of our proposed research in Phase III.

Context of the California Current System (CCS) and Ecosystem (CCE)

The California Current is the eastern limb of the large, clockwise circulation of the subtropical gyre of North Pacific Ocean (Fig. 7). As part of the water from the Westwind Drift turns southward and becomes the California Current, it carries cool, fresh water from the Subarctic. The California Current *System* off central and southern California consists of the broad, eddy-rich southward flowing California Current (CC), a persistent but variable subsurface California Undercurrent (CUC) centered on the continental slope that carries water of tropical origin poleward, and a circulation over and near the continental shelf that is energetic and highly seasonal, shifting from a wind-driven equatorward flow and coastal upwelling in spring-summer to poleward flow in fall-winter (Hickey 1998).

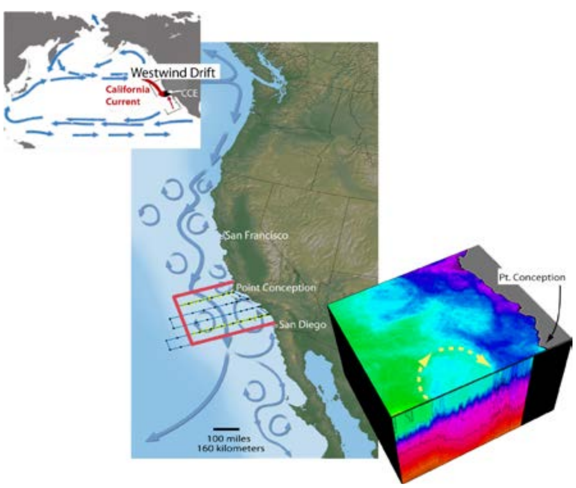

Fig. 7. Schematic views of the circulation of the California Current System (CCS) on 3 spatial scales: (top) Basin Scale, (middle) Regional Scale, and (bottom) Mesoscale.

Along much of the U.S. west coast, especially during the spring and summer, the North Pacific High pressure system yields winds from the north that drive near-surface waters offshore by Ekman transport, and cool nutrient-rich water from below is advected toward the surface in the near-shore zone. This wind-driven coastal upwelling is a characteristic feature of eastern boundary currents (Hill et al. 1998). Upwelling also occurs offshore beyond the coastal margin, associated with curl of the wind stress (i.e., upwelling induced by an onshore-to-offshore gradient in the intensity of alongshore winds; see Fig. 6). The mean circulation of the CC includes several large-scale meanders linked to coastal promontories (Centurioni et al. 2008). Closer to the shoreline, coastal upwelling jets occur during upwelling events in spring and summer months (Barth et al. 2000). The CC and the upwelling jets are unstable and produce vigorous mesoscale variability (Marchesiello et al. 2003), with jets and filaments that carry upwelled water hundreds of kms offshore, and sharp fronts and well-defined eddies, particularly during the upwelling season and near coastal promontories. Eddy energy varies with the seasons, typically peaking in summer, and eddies propagate energy westward away from their generation regions in the CCS (Kelly et al. 1998, Strub and James 2000, Di Lorenzo 2003; Chelton et al. 2011). Mesoscale energy also varies interannually (Keister and Strub 2008). Mesoscale eddies have typical velocities of 30 cm s^{-1}, as large as the CC core, with peaks of 80 cm s^{-1}s (Chereskin et al. 2000, Davis et al. 2008). Eddy amplitudes (anomaly of 0.15 dyn m) can be as large as the total steric height increase across the CC; hence, the mean southward flow of the CC is often disrupted by strong mesoscale features (Fig. 7).

Point Conception, near the northern boundary of our study region, is a coastal promontory associated with strong upwelling and mesoscale variability. The sharply angled coastline has a marked effect on coastal winds (Winant and Dorman 1997), but the CC continues southward, while a series of submarine banks and ridges extend the continental barrier on the inshore side of the current. Inshore, the southward moving mix of subarctic and upwelled waters interacts with warm-water intrusions from offshore and the south. Together these form a counterclockwise circulation pattern, the Southern California Eddy, which dominates the Southern California Bight (Dong et al. 2009) apart from spring (Strub and James 2000).

The strength and location of the CC and of the inshore circulation vary seasonally, interannually and interdecadally in response to large-scale changes in ocean/climate patterns. The northern CC is mainly driven by changes in the Aleutian Low and is associated with the Pacific Decadal Oscillation (PDO) pattern of SST (Chhak et al. 2009). The southern CC is driven by the changes in the North Pacific Oscillation (NPO) that is associated with the North Pacific Gyre Oscillation (NPGO) pattern of SST, as well as by the PDO. Remote forcing from the tropics, associated with ENSO, also drives CC variations through coastally trapped poleward propagating oceanic waves and related atmospheric teleconnections.

The CCS has pronounced onshore-offshore differences in nutrient delivery mechanisms and food-web structure along the California coastline (shown schematically in Fig.6; Rykaczewski and Checkley 2008). The main physical driver is the cross-shore gradient in surface wind stress, which peaks offshore, a phenomenon accentuated in our region by the sharp southeastward break in the orientation of the coastline south of Point Conception. Close to the coastal boundary, offshore Ekman transport of surface waters under upwelling favorable (equatorward) winds draws cold, nutrient-rich water (including iron infusions from the sediments) into the euphotic zone, resulting in strong blooms of larger phytoplankton (diatoms and dinoflagellates), which in turn support elevated concentrations of large consumers, notably large calanoid copepods and euphausiids. This classic coastal upwelling domain (anchovy habitat) is characterized by a shallow euphotic zone and productive but unbalanced food web where growth exceeds losses due to consumption (Landry et al. 2009), promoting rapid biomass accumulation and ultimately large export. Farther offshore (sardine habitat), the horizontal shear in wind stress (wind stress curl) drives a more subtle Ekman divergence of surface transport that delivers water from the deeper nutricline into the base of the euphotic zone. Nutrient fluxes associated with curl-driven upwelling are small per unit area compared to traditional coastal upwelling, but substantial in the aggregate because they occur over a much larger area. As shown schematically in Fig. 6, the lower nutrient flux selects for smaller primary producers (flagellates and cyanobacteria) that compete more effectively for nutrients at low concentrations. They are regulated by small protistan consumers, resulting in a tight coupling of growth, grazing, and nutrient recycling. The offshore region is characterized by strong density stratification and a deep maximum in chlorophyll *a* (and microbial biomass) at the base of the euphotic zone, where diminishing light meets the top of the nutricline.

The CCE region is a major center of spawning of epipelagic fishes (including Pacific sardine, northern anchovy, Pacific hake, jack mackerel), many of which migrate extensive distances to spawn in this region in preference to upwelling centers elsewhere in the California Current System (Saunders and McFarlane 1997, Smith and Moser 2003). The preference for this habitat has been hypothesized to relate to the more retentive ocean circulation in the region (e.g., Parrish et al. 1981, Bailey 1981) and, in the case of sardines, to the prey size spectrum favored in the curl-driven upwelling region (Rykaczewski and Checkley 2008). The large historical variations in landings of these fishes have been attributed to the interaction of natural ecosystem variations (cf. Fig. 6) and human fishing decisions (Jacobson et al. 2001, Hsieh et al. 2005). In CCE Phase II, it became clear that the CCE region is an important spawning habitat for mesopelagic fishes as well (Davison 2011, Bowlin 2015, Netburn 2016) and a surprising finding was that the biomass of mesopelagic fishes, including myctophids, gonostomatids, bathylagids, and others is comparable to or great than that of the coastal epipelagic fishes (Davison et al. 2015b).

Cross-shore fluxes in the CCE

Since the inception of the CCE site, we have identified temporal changes in the rates of cross-shore transport as one of our four hypothesized mechanisms leading to ecosystem shifts. In earlier funding cycles we addressed cross-shore transport primarily via ROMS models of nearshore circulation, including both offshore-propagating eddies and Ekman transport (e.g., Combes et al. 2013, Davis and Di Lorenzo 2015b, Chenillat et al. 2015). **In this renewal, we propose for the first time to observationally address cross-shore transport at sea, as mediated by mesoscale features such as coastal filaments and eddies.**

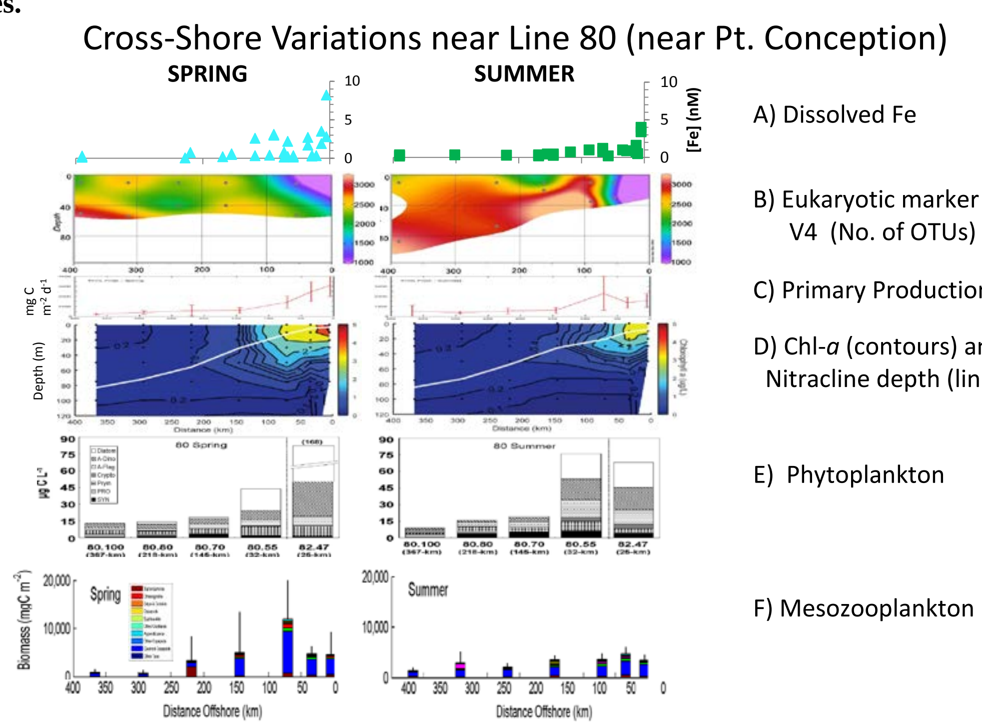

Fig. 8. Cross-shore variations near CalCOFI Line 80, off Pt. Conception in Spring and Summer. (A) Dissolved Fe (King and Barbeau 2011), (B) Microbial diversity at Eukaryotic marker V4, from metabarcoding and associated sequencing on the MiSeq platform (A. Allen, unpubl.), (C) CalCOFI-measured primary production and (D) Chl-*a* (R. Goericke unpubl.), (E) phytoplankton C biomass and community composition (Taylor et al. 2015), and (F) mesozooplankton C biomass and community composition by ZooScan (M. Ohman unpubl.).

Consequences of cross-shore transport - There are strong cross-shore gradients in Fe, microbial diversity, nitrate, primary production, phytoplankton C biomass and community structure, and mesozooplankton C stocks and community structure in the CCE region (Fig. 8, line 80), as might be expected in a coastal upwelling ecosystem. Cross-shore transport therefore usually results in a net flux in the offshore direction, although return flow by eddies and upwelling must also be considered. Historic CalCOFI sampling illustrates the importance of cross-shore tending filaments that entrain coastal plankton, such as the euphausiid *Thysanoessa spinifera*, and transport them offshore (Fig. 9A, Brinton 1981, Haury et al. 1986). Satellite imagery corroborates the importance of such features (Fig. 9B). However, the magnitude of fluxes and their variability over time will depend on the magnitudes of horizontal gradients, specific physical transport mechanisms, vertical sinking and subduction, and the biological transformations that occur in transit. We propose to characterize these processes during a sequence of three experimental cruises during CCE Phase III.

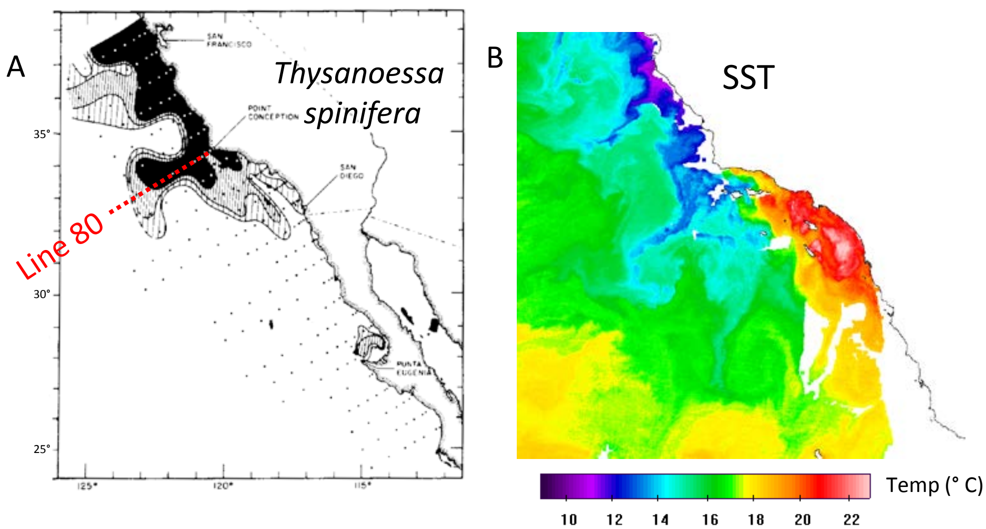

Fig. 9. (A) Distribution of the cool-water, coastal euphausiid *Thysanoessa spinifera*, in June 1978, from Brinton (1981; also reproduced in Haury et al. 1986), illustrating the cross-shore distribution in the vicinity of Pt. Conception near CalCOFI line 80. (B) Satellite Sea Surface Temperature image of a cool water filament tending offshore near Pt. Conception, on 1 July 2007.

Mesoscale and submesocale features such as filaments and eddies can transport organisms, detrital organic matter, and nutrients offshore to distances ranging from 100-300 km (e.g., filaments, Mackas et al. 1991, Keister et al. 2009b) to >800 km (e.g., eddies; Barth et al. 2002, Bograd and Mantyla 2005, Gruber et al. 2011, Nagai et al 2015). It has long been pointed out that there is a spatial de-coupling of primary production and vertical export in the California Current System (CCS), and, by implication, in other Eastern Boundary Current upwelling systems. Although the classical textbook relationship suggests that New Production = Export Production at steady-state, this relationship does not apply in advective systems. Olivieri and Chavez (2000) found that upwelling-induced advection was the dominant loss term for primary production in Monterey Bay. Plattner et al. (2005) illustrated that New Production greatly exceeds Export Production close to shore in the CCS, while the two are more closely balanced ca. 300 km offshore. They stated: "*This horizontal transport divergence of organic nitrogen is driven in part by the mean Ekman-induced offshore transport, but includes a substantial component driven by persistent meso- and submesoscale features.*" Gruber et al. (2011) illustrated how eddy-induced offshore transport can deplete nitrate in the euphotic zone nearshore and, due to offshore subduction of nutrients below the euphotic zone, diminish overall primary production. Nagai et al.'s (2015) modeling study suggested that offshore transport is a major component of any material budget in the CCS and that "*this transport is largely controlled by mesoscale processes, involving filaments and westward propagating* *eddies…providing the key mechanism for long-range transport of nitrate and organic matter from the coast deep into the offshore environment*."

Direct evidence from previous CCE studies corroborates the importance of cross-shore lateral transport. Stukel et al. (2011) illustrated from a trophic cycling model parameterized with CCE data that f-ratios (**New Production:Total Production**) are much higher than e-ratios (**Export Production: Total Production**) within the first 100 km of the coast, but this imbalance declines markedly in the offshore zone (Fig. 10A). They stated that "*e-ratios were strongly decoupled from new production estimates*." Stukel et al. (2013) showed that the greatest imbalance occurred at the highest rates of primary production, which occur closer to the coast. Unpublished work by B. Stephens and L. Aluwihare in CCE extends the analyses of Stukel et al. by considering dissolved as well as particulate organic C production and export. Their results reinforce the spatial decoupling of New Production from Export fluxes (Fig. 10B), and point to the elevated importance of dissolved organic carbon (DOC) production closer to shore.

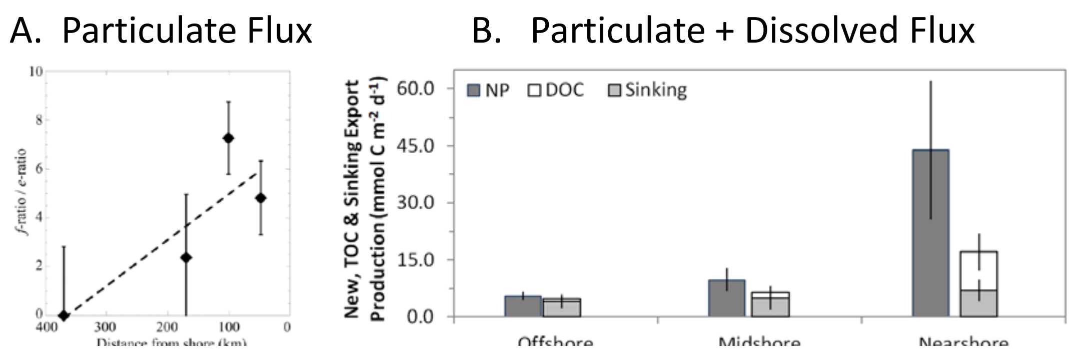

Fig. 10. Cross-shore imbalance between New Production and Export Production. (A) Particulate fluxes, expressed as f-ratio/e-ratio (Stukel et al. 2011), and (B) Comparison of new production (NP) with total organic carbon export (TOC), where TOC is the sum of sinking particulate organic carbon (POC) and laterally-advected dissolved organic carbon (DOC) (B. Stephens and L. Aluwihare unpubl.).

A recent synthesis of CCE studies (Stukel et al. in review) illustrates one mechanism contributing to the spatial imbalance of new and export production, namely front-related particle export. Stukel et al. demonstrate along-isopycnal (i.e., constant density surfaces) subduction of the high ^{234}Th deficiency water from the coastal side of a front toward the offshore (Fig. 11). A comparison of export fluxes at this frontal feature with prior measurements in the CCE region shows that eddy-related fronts can markedly enhance export of organic matter, in both particulate and dissolved forms (Stukel et al. in review, Fig. 12).

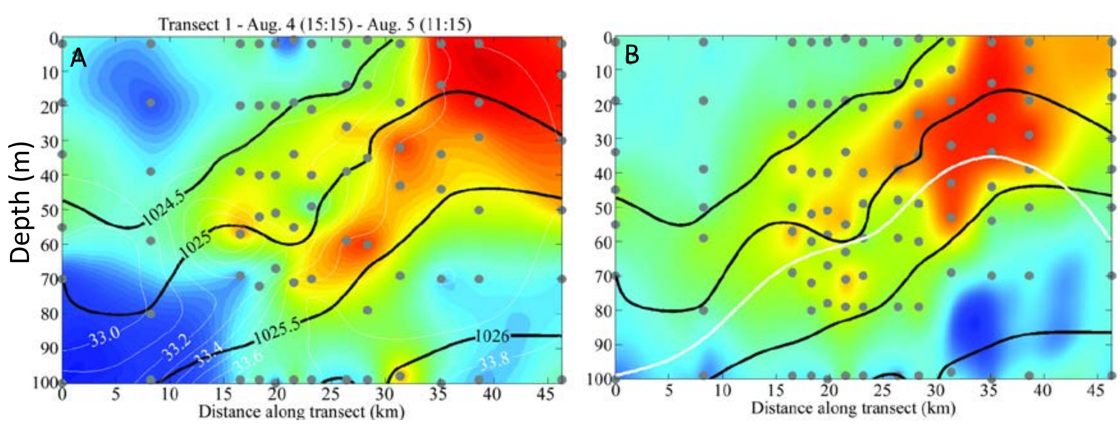

Fig. 11 – Subduction across the E-Front on P1208. (A) Vertical section of ^{238}U- ^{234}Th deficiency. (B) Vertical section of Particulate Organic Carbon concentration. Black lines are seawater density. White lines show depth of the euphotic zone (0.1% light level). From Stukel et al. (in review)

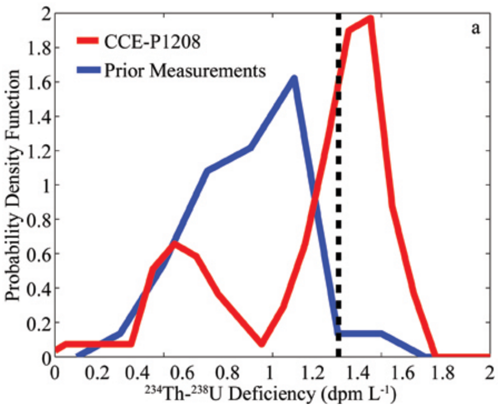

Fig. 12. – **Front-related export.** Comparison of CCE-P1208 export measurements as front-related surface layer ^{234}Th deficiency on P1208 (red) in relation to all prior measurements made on CCE-LTER cruises in non-frontal regions (blue). From Stukel et al. (in review).

Hence cross-shore transport has pronounced consequences for both population dynamics and biogeochemical cycling in the CCE.

Mesoscale features as cross-shore transport mechanisms – Filaments are characteristic of most eastern boundary currents (e.g., Stevens and Johnson 2003, Sangra et al. 2015, Rossi et al. 2013). They usually contain a long core of cold water that originates from the upwelled water near the coast. They have cross-filament scales of 10-50 km, and along-filament scales of 50-200 km. The balance of forces within filaments makes them very efficient vehicles for transporting material offshore (e.g., Nagai et al. 2015, Muller et al. 2013, Morholz et al. 2014).

Filaments form through an interaction of the wind-driven upwelling front with coastal topography and bathymetry (e.g., Strub et al. 1991, Haidvogel et al. 1991, Walstad et al. 1991, Marchesiello et al. 2003, Meunier et al. 2010). Filament formation is tied to the strength of upwelling-favorable winds; thus filaments have a seasonal cycle. Filaments typically terminate in either an eddy dipole, or a cyclonic eddy that propagates westward at ~2 km d^{-1}, leading to a net offshore transport of coastal material (Nagai et al. 2015). Cross-shore transport in filaments is much larger than the Ekman flux (Muller et al. 2013).

Filaments are usually characterized by a cold core, leading to doming of isopycnals along the axis of the filament, with lighter water to the sides (Fig. 13B). For a filament stretching westward, this central doming leads to geostrophic currents directed to the west along the northern flank, and to the east along the southern flank (McWilliams et al. 2009, 2015). Filaments also have strong ageostrophic flows, with

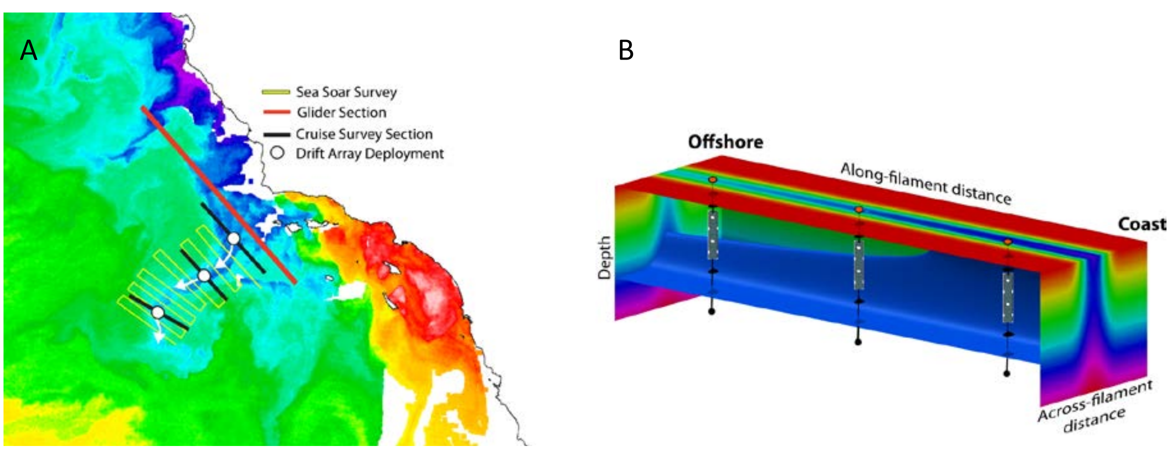

Fig. 13. (A) Illustration of sampling design across a coastal filament (blue=cold water). (B) Idealized representation of a cross-shore coastal filament, illustrating cold water (blue) upwelled near the coast, then advected and subducted offshore. Lagrangian driftarrays illustrate deployment of in situ seawater dilution experiments and phytoplankton growth chambers. (Peter Franks)

intense downwelling along the central axis (McWilliams et al. 2009, 2015, Gula et al. 2014), or on the northern side (Nagai et al. 2015), with upward return flow displaced to the north and south of the main axis. Vertical velocities intensify along the filament axis, with predominance of upwelling near the coast and downwelling farther offshore, giving net upwelling integrated over the filament length (Nagai et al. 2015). Downwelling velocities of 10s of m d^{-1} can lead to significant subduction of surface material.

Previous filament studies in the CCS have focused on the California Current Jet (e.g., Barth et al. 2002). Plankton transport has been analyzed in filaments off Pt. Arena (Mackas et al. 1991, Smith and Lane 1991) and Cape Blanco (Keister et al. 2009b). Thus far, the formation of filaments at Point Conception has been relatively poorly explored. Here the coastline makes an abrupt bend to the east to form the Santa Barbara Channel (SBC) and the Southern California Bight (SCB). A cool pool often forms between Point Conception and Point Arguello to the north (Sverdrup 1938) when upwelled waters to the north meet waters flowing northward along the coast of the SCB (Barth and Brink 1987, Winant et al. 1999, 2003). Where these currents meet, a cold filament forms and propagates 10s of km offshore toward the west or southwest before turning S or SE where it can be tracked for hundreds of km (Centurioni et al. 2008, Drake et al. 2011, Kim et al. 2011). Programs have investigated a cyclonic eddy that forms regularly to the south of the filament (e.g., Atkinson et al. 1986, Haury et al. 1986, Simpson et al. 1986). We intend to make the filaments that form off Pt. Conception a particular focus of our experimental process studies.

Mesoscale eddies are a prominent feature of the CCS, particularly off Oregon to Pt. Conception (Chelton et al. 2007, 2011, Davis and DiLorenzo 2015). South of Point Conception, eddy kinetic energy is weaker, though eddy cores cover about 10% of the CCE study region at any given time (Haury et al. 1986, Chenillat et al. in review). Eddies propagate westward at about 2 km d^{-1}, with cyclonic eddies tending to the northwest and anticyclonic to the southwest due to the beta effect (Marchesiello et al. 2003). Eddies tend to contain trapped cores of coastal source waters where they were formed. Other waters subsequently wrap around the growing eddies, separate from the coastal front, and propagate offshore.

Cross-shore Flux Studies: Research objectives, hypotheses and approaches

Mesoscale features such as filaments and eddies can contain a predictable population gradient driven by processes of mixing, nutrient drawdown, and community evolution. They are thus excellent natural laboratories for studying these processes that are likely to change as a result of increased coastal wind stress. ***Our primary objective in studying these features is to understand and quantify key mechanisms that transport coastal production and populations offshore in the CCE region, including the magnitudes and length scales of transport and their climate sensitivities.*** We will address three specific hypotheses related to mesoscale features and cross-shore transport:

H_1: Lateral transport dominated by the interaction of Ekman transport, coastal filaments, and westward-propagating eddies provides a significant flux of nutrients and organisms to offshore waters. Variability in lateral transport strongly impacts the offshore extent of these fluxes.

H_2: Carbon export associated with offshore transport is determined by in situ evolution of communities and nutrient regimes, and by subduction occurring largely at sharp frontal density gradients.

H_3: Increased cross-shore fluxes of nutrients and organisms in the CCE region will be associated with long-term increases in winds and eddy kinetic energy, as well as with large-scale climate variability.

Addressing these hypotheses will require a focused, multidisciplinary approach spanning multiple spatial and temporal scales. At the core of our plan is a series of three Process studies that will each combine:

(1) **Autonomous coastal measurements** by gliders, satellites, moorings, and coastal radar. A *Spray* glider will operate along north-south transects in order to estimate cross-shore fluxes of water, nutrients, and organisms. These estimates will be combined with satellite-based estimates of the

seasonal timing, spatial extent, and velocities associated with coastal filament and eddy-related transport.

(2) **Lagrangian process cruises** that characterize community vital rates *in situ* together with mesoscale mapping of across- and along-feature variability in plankton populations. Analyses will include net community growth, grazing, and export rates along the cross-shore axis of a feature, together with microbial gene expression and metazoan population structure.

(3) **Modeling** studies will utilize data from (1) and (2) to analyze mechanisms of cross-shore fluxes and predict how such features may evolve with changing climate.

Remote and Autonomous Measurements*:* Mesoscale features are dynamic, hence we will use a suite of autonomous measurements currently in place within the CCE domain to assess the development and age of the features of interest and stage our cruise activities accordingly. Remote/autonomous measurements that we will use include: (1) **Satellite remote-sensing** of Sea Surface Temperature, Chl-*a*, Sea Surface Height (Kahru et al. 2015), and Sea Surface Salinity; (2) **High Frequency coastal radar (CODAR).** The CODAR network (Harlan et al. 2010) provides a real-time assessment of surface currents that can be used to identify and track strong offshore velocity signatures of filaments. These observations are also assimilated in real-time ocean model nowcasts and forecasts (e.g., Zhijin et al. 2008), providing estimates of surface velocity, temperature, and pycnocline depth much further offshore than CODAR can sample; (3) ***Spray*** **gliders** equipped to measure temperature, salinity, density, phytoplankton Chl-*a*, zooplankton acoustic backscatter, and Doppler currents from the sea surface to 500 m. These gliders regularly operate along CalCOFI Lines 80 and 90 in a program directed by D. Rudnick, making repeat cross-shore transects (Davis et al. 2008; Powell and Ohman 2015). We will also add a north-south, alongshore glider line (Fig. 13A) extending ca. 100 km to the north and to the south of Pt. Conception in order to quantify cross-shore fluxes during the period before, during, and after each process cruise; and (4) **CCE moorings** equipped with sensors similar to those on the gliders, but also pCO_2, pH, nitrate and multi-wavelength radiometers (Ohman et al. 2013). The two moorings are located near the filament and eddy generating region ~35 km from Pt. Conception (CCE2, Fig. 15, p. 23) and ~225 km offshore (CCE1, Fig. 15) in the path of both filaments and eddies. These autonomous measurements will also be used to analyze the temporal evolution of features during our study period, and (in conjunction with CalCOFI measurements) to ascertain the temporal frequency and spatial extent of these features, to place our cruise measurements in the context of seasonal, interannual, and decadal scale variability.

Mesoscale Mapping: We intend to focus our experimental studies on a prominent cross-shore filament. However, our contingency plan is to focus on an eddy, if no filament is detectable during a scheduled process cruise. Initial shipboard 3-dimensional spatial mapping of features of interest (filaments and eddies) and adjacent waters will be made with a SeaSoar (Fig. 13A; cf. Rudnick and Luyten 1996, de Verneil and Franks 2015) that makes repeated profiles of temperature, salinity, fluorescence, O_2, particle biovolume and size spectra (via LOPC), and optical backscatter (to estimate POC, Briggs et al. 2011) to 300 m. This profiling will include deeper features associated with subduction fronts. Downwelling along the axis of filaments can carry nutrients and particulate material to depths as great as 150-200 m (Bograd and Mantyla 2005, Ngai et al. 2015, Barth et al. 2002, Stukel et al. in review) within 10+ days. To complement SeaSoar data, near-surface samples from the ship's flow-through system will allow us to measure 2-dimensional along- and across-feature variability in nutrients, Chl-*a*, POM and TOM, net community production (O_2:Ar), phytoplankton taxonomic composition (HPLC, Advanced Laser Fluorometry, microbial metagenetics), and ^{234}Th. These measurements (many in real-time), will allow us to target specific regions for transect studies and our quasi-Lagrangian experimental cycles.

Cross-Frontal Transects: A limited suite of CTD-rosette profile measurements will be used to initially characterize chemical constituents and biological standing stocks along three cross-filament transects: (1) nearshore, near the site of filament generation, (2) at an intermediate distance offshore, where communities and chemistry have evolved relative to site (1), and (3) further offshore in the mature feature

(Fig. 13). These transects will cut across the feature, sampling sites outside as well as across the filament in order to resolve gradients across the fronts that form on each side of the filament. If we instead focus on an eddy, a similar approach will be taken that crosses entirely through the feature, extending across the frontal boundaries and well outside it, in two orthogonal transects through the eddy center.

Quasi-Lagrangian Experimental Cycles*:* Short-term (~3-day) quasi-Lagrangian process studies will allow us to quantify the processes driving biological and biogeochemical changes along the onshore-offshore gradient of the mesoscale features of interest. An experimental Cycle of activity (4-5 days each) will be conducted in each of the three environments described above, along the axis of a filament (Fig. 13) followed by a shorter comparative Cycle (2-3 days) in the offshore region off the axis of the filament. Small-scale (ca. 20-25 km) surveys will first be done with a Moving Vessel Profiler (T, S, Chl-a, LOPC) (Ohman et al. 2012) to characterize local gradients. Then a Cycle will begin and end with the deployment and recovery of a drifting sediment trap and autonomous optical Carbon Flux Explorers (Bishop et al. 2009, Bishop et al. 2016), complemented by ^{234}Th measurements (Stukel et al. 2015). Previous CCE process cruises have shown that contemporaneous use of in situ incubations, mesozooplankton net sampling, deckboard trace metal incubation experiments, sediment trap and Th disequilibrium, and trace metal:nutrient ratios has allowed us to constrain the primary growth and loss terms for phytoplankton, measure the limitation patterns of primary producers, and determine the mechanisms controlling biogeochemical fluxes in CCE water parcels (King et al. 2012, Krause et al. 2015, Landry et al. 2009, Stukel et al. 2011, Stukel et al. in review). These measurements will be complemented by studies of the composition of sediment trap material, bacterial production rates, transformations of dissolved organic matter (Meador and Aluwihare 2014), and microbial communities and interactomes (Zeigler-Allen et al. 2012, Dupont et al. 2015, Fuhrman et al. 2015) along the axis of the filament. Primary production and New Production will be quantified by $H^{14}CO_3^-$ and $^{15}NO_3^-$ incubations, respectively (R. Goericke, M. Stukel). In situ seawater dilution experiments at 6-8 light depths will measure phytoplankton growth and microzooplankton grazing rates, and size-fractionated gut fluorescence will assess mesozooplankton grazing (Landry et al. 2009). MOCNESS sampling will characterize changing vertical distributions of mesozooplankton (Ohman and Romagnan 2016). EK60 multi-frequency acoustics will provide an index of euphausiid and fish biomass (Lara-Lopez et al. 2012). These experimental cycles will: 1) target specific regions relative to the feature (formation region, mid-filament, offshore extent of filament); 2) examine growth and loss of specific phytoplankton and bacterial taxonomic groups (using pigment and metagenomic techniques) in response to changing zooplankton grazing pressure and nutrient regimes, allowing us to quantify the processes controlling community evolution along the mesocale feature; and 3) examine mechanisms of carbon and nutrient removal operating in the features of interest.

If our target feature is instead an eddy, we will conduct three 3-day experimental Cycles in the coastal upwelling region nearshore and three comparable experimental Cycles further offshore in the eddy core, in order to contrast community composition, growth, grazing, export, and vertical habitat usage inside the eddy with food web structure and growth/export imbalance in the nearshore zone.

Molecular Tools: In an augmentation of our previous measurements of microbial diversity during Process cruises, A. Allen and B. Palenik will analyze the temporal evolution of microbial networks along coastal filaments or in eddies using comparative genomics, metagenomics, and metatranscriptomic approaches during transects and Lagrangian cycles. This will permit resolution of rates of change in microbial network membership, associated physiological status, and biogeochemical impacts of viruses, bacteria, and microbial eukaryotes along these features.

Modeling syntheses*:* The great strength of the quasi-Lagrangian approach is obtaining biological rate measurements that are little influenced by advection, which are invaluable for parameterizing and testing models. The models then provide a detailed, well-resolved physical context in which to interpret the observations. We will continue to use complementary modeling approaches to synthesize and analyze the data: 1) data are assimilated into the ROMS model, which can then be used with its adjoint to provide physically consistent flow fields and forcings for interpreting chemical and biological observations (Song et. al 2012, Stukel et al. in review2) Data are used to parameterize coupled physical-biogeochemical-ecosystem models (e.g., ROMS-NEMURO) that can be used to test specific hypotheses and explore dynamics through numerical experimentation (Li et al. 2010, 2011; Chenillat et al. 2013, 2015). 3) Data are also used to constrain dynamic models to provide consistent flow fields that can then be used to understand rate processes in the region (de Verneil and Franks 2015). 4) Inverse models parameterized with observations will provide information on unmeasured processes (e.g., Stukel et al. 2012). Each of these approaches will provide estimates of the relative contributions of in situ rates and physical processes in generating the observed changes and spatial/temporal patterns. We will thus quantify and verify the processes responsible for the transport and transformation of organic matter, and the spatial/temporal scales over which these mesoscale features exert an influence.

Approaches to address alternative mechanisms underlying ecosystem transitions

Apart from our Process study focus on cross-shore transport, we will continue to address our three alternative mechanisms underlying ecosystem transitions (see Fig. 6):

Anomalous alongshore advection: The importance of sustained, anomalous alongshore advection as a mechanism leading to changes in biological assemblages, and maintenance of altered assemblages, will be addressed by calculating north-south volume transports through the cross-shore trending lines in the LTER sampling domain. Vertically integrated transports will be obtained from the CORC (Consortium for the Ocean's Role in Climate) program, led by CCE Associate U. Send. These geostrophic and satellite altimetry estimates will be compared with transports computed from the dynamic topography obtained on quarterly CalCOFI cruises, and by *Spray* gliders (D. Rudnick), in order to assess whether changes in the biota are coincident with altered transports. Higher frequency sampling at the CCE-1 and CCE-2 moorings (equipped with ADCPs) will resolve finer temporal resolution of variations in transport.

In situ food web changes: We will continue to utilize a *space-for-time exchange*, i.e., exploiting natural spatial variability across the CCE region as an analog of how food web structures and rate processes will respond to temporal changes in environmental forcing. Our experimental process studies, while addressing cross-shore transports, will naturally sample regions of different characteristic nitracline depths, phytoplankton floristics, and water-column hydrography, spanning end-member states of pelagic ecosystem structure (from coastal upwelling, to curl upwelling, to stably stratified) and a continuum of conditions in between. Our concurrent time-series measurements will enable us to test the assumption that variations in space are appropriate analogs for variations over time.

***Altered predation pressure*:** We will test the hypothesis that variations in zooplanktivory explain the temporal dynamics observed in CCE euphausiids (Fig. 1A). Krill biomass has been increasing over the duration of previous CCE support, while the biomass of hake, sardine, and anchovy has been in decline, suggesting that krill could be responding to changes in predation pressure, as well as to climatic factors. We will investigate the role of zooplanktivory in explaining (a) a long-term progressive increases in overall euphausiid biomass and (b) low-frequency shifts in population dynamics exemplified by *Nyctiphanes simplex* (Di Lorenzo and Ohman 2013). We will synthesize existing biomass data on krill predators, dietary specificity, and daily rations. The predators of primary interest are zooplanktivorous fishes and carnivorous zooplankton. As revealed in the California Current Predator Diet Database (Szoboszlai et al. 2015), adult age classes of euphausiids form the vast majority of the diet of Pacific hake, blue whales, and some seabirds (e.g., Cassin's auklets). Early age classes of krill are consumed by epipelagic nekton such as sardine, anchovy, and market squid, and by a variety of carnivorous zooplankton (Suchman et al. 2008). Variations in epipelagic zooplanktivorous fish stocks are determined by colleagues at the Southwest Fisheries Science Center/NMFS. The biomass of mesopelagic zooplanktivorous fishes will be estimated from trawl surveys (Davison et al. 2015a, Netburn 2016). Variations in abundance of carnivorous zooplankton (esp. jellyfish, siphonophores, chaetognaths) will be assessed from the CalCOFI zooplankton samples. Bioenergetic models will be used to estimate consumption (Nonacs et al. 2001, Davison 2011). We will integrate this estimate of natural mortality into models of krill population dynamics in relation to climatic factors. This research is important because top-down impacts on the CCE ecosystem have yet to be adequately tested, and understanding the dynamics of krill is important to fisheries and wildlife populations in the region.

Ecological Forecasting of ENSO in the California Current Ecosystem

In the CCS, El Niño-Southern Oscillation (ENSO) exerts strong impacts on a wide range of physical and biotic phenomena including temperature, ocean circulation, nutrients, primary and secondary production, and the geographic distribution of diverse types of organisms. We have identified ENSO as the dominant element of our ecological disturbance regime since the inception of CCE. Despite the extensive empirical observations made by CCE and others on the U.S. west coast, there is no quantitative framework in place for developing predictive forecasts of the biotic effects of ENSO on the pelagic ecosystem in mid-latitudes. This is in marked contrast to the physical climate community, where ENSO forecasting has become routine. Extensive TAO-Triton mooring infrastructure along the equator is linked to diverse model-based dynamical and statistical forecasts. Climate Prediction Center forecasts of physical effects of ENSO are regularly updated and widely accessible. We now plan an explicit effort in CCE to develop a framework to identify key indicators of ENSO, both physical and biotic, along the U.S. west coast; to develop a quantitative framework for understanding the functional relationships between ENSO physical changes and biotic responses; and to refine this understanding into specific model-based forecasts. This will be a long-term effort, but we consider it essential to begin now. This effort will be coordinated with others along the U.S. west coast.

Understanding the predictability and dynamics of eastern boundary current upwelling ecosystems is an emergent priority among various international science organizations (e.g. CLIVAR, PICES, ICES) because of its key societal impacts. Given the wealth of existing observations and knowledge of climate and ecosystem dynamics in the CCS, exploring the predictability of marine ecosystems that arises from ENSO is a prime case study to make progress at the nexus of climate and marine ecology. In CCE Phase III, we will develop a framework for using existing ENSO physical forecasts (e.g., by NOAA's Climate Forecast System) to predict changes in the pelagic ecosystem in the CCS. Our goal is to identify the predictable components of the physical climate system that can be used to forecast key aspects of organismal and ecosystem responses on monthly, seasonal, and multi-season time scales. We envision four primary research tasks. **Task 1: Regional mechanisms impacting key ecosystem indicators.** The goals are to: (1) identify a set of key ecosystem indicators that characterize ecosystem state, both in terms of ecosystem function and ecosystem services provided; and (2) identify the regional processes (direct physical influences, as well as bottom-up and top-down trophic control) that generate predictable responses in these key indicators. **Task 2: Impacts of ENSO diversity on ecosystem drivers.** Along the U.S. West Coast, ENSO impacts can differ greatly among different ENSO events. This reflects the diverse flavors (central Pacific, eastern Pacific; Capotondi et al. 2015) of the tropical expression of ENSO and their teleconnection to higher latitudes (Fig. 14 and caption). The goal of this task is to quantify how different types of ENSO may impact the ocean, atmospheric teleconnections, and ecosystem drivers in the CCE region. **Task 3: Dynamical and statistical modeling for ecosystem forecasts.** This will build on existing CCE modeling efforts to develop an improved set of dynamical and/or statistical models that use the mechanistic information identified in Tasks 1 and 2 to forecast the ENSO impacts on the CCE, together with uncertainties. **Task 4: Data streams and operational ecosystem forecasts.** This will identify the technical challenges of implementing operational forecasts of ENSO impacts on the CCE. These include: (1) prioritizing ecological indicators to forecast, (2) obtaining real time access to the required data streams for model forecasts and potentially developing new data streams, (3) providing uncertainty estimates, and (4) developing communication strategies to stakeholders and the public.

As a first step toward such forecasts, we have already received support from US CLIVAR and OCB to conduct a workshop on "***Predictability of U.S. West Coast Ecosystems Based on ENSO Forecasts***" in summer 2016. The workshop is organized to advance the research tasks outlined above, in collaboration with other research institutions along the U.S. West Coast. By leveraging the observational and modeling strength of ongoing research efforts, CCE-LTER will take a leadership role in combining long-term observational records with quantitative models to forecast changes in key environmental states. This forecasting focus is also directly linked to our NSF-supported RAPID cruise scheduled for spring 2016, which will provide direct experimental measurements of impacts of the major El Niño of 2015-16 on key rate processes in the CCE pelagic ecosystem.

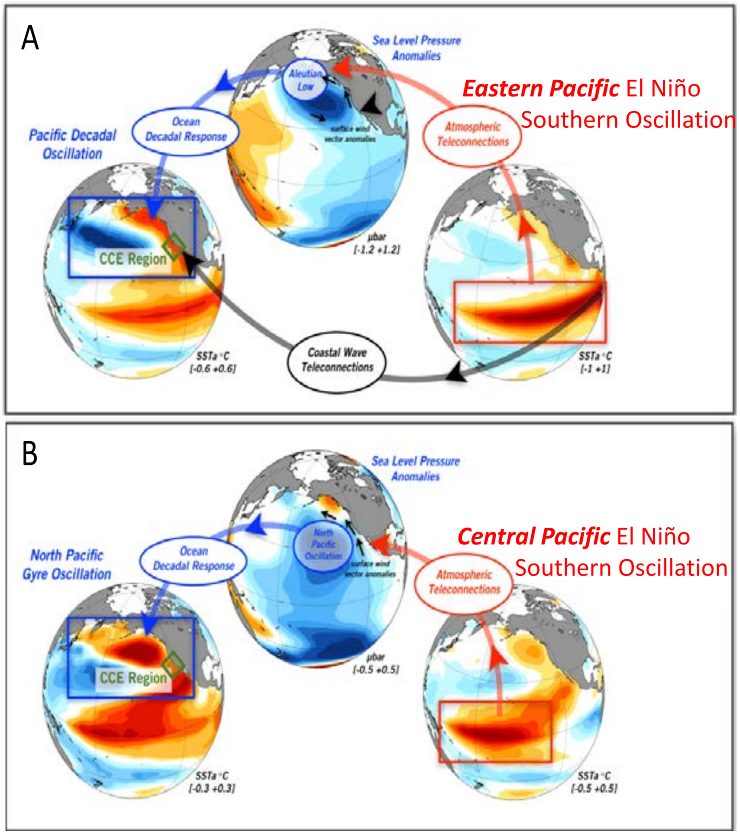

Fig. 14: Hypothesized El Niño teleconnections to the NE Pacific. (A) During a strong Eastern Pacific El Niño the peak SST anomalies re-arrange the atmospheric teleconnections that affect the strength and location of the Aleutian Low. Changes in the Aleutian Low force the extra-tropical oceanic response of the PDO, a strong physical and ecological driver of the CCE. The eastern Pacific El Niño also exhibits positive SSHa along the coast of South America together with the high SSTa. SSHa anomalies propagate poleward as coastal wave teleconnections and depress the thermocline along the coast, which contributes to upwelling suppression and favors warmer SSTa. (B) During a strong Central Pacific El Niño the SSTa are displaced toward the dateline and rearrange the atmospheric teleconnections that affect the strength and location of the North Pacific High pressure system. Changes in the North Pacific High force the extra-tropical oceanic response of the NPGO. The Central Pacific expression does not excite a coastal wave teleconnection. (Emanuele Di Lorenzo)

Our collaborative efforts on ENSO forecasts will provide excellent opportunities for comparative work with colleagues along the U.S. West Coast. ENSO is also a topic we will develop with the Palmer Station LTER site (discussions held at the LTER All-Scientists Meeting, Sept. 2015). ENSO has surprisingly broad impacts across U.S. LTER sites (e.g., Ohman and Kratz 2013), furnishing an excellent opportunity for other cross-site interactions. In addition, NCAR (PI: Matt Long), DOE, and CCE have recently developed a partnership to develop a food web model for the California Current Ecosystem. A postdoctoral scholar will be employed by NCAR and have access to their high-performance computing environment, while working in close collaboration with CCE scientists.

Core LTER Research Areas

In the course of our hypothesis-oriented research in the CCE LTER site, we will continue to address core measurements held in common among all LTER sites. Many of these measurements are made in collaboration with CalCOFI (Fig. 15).

Pattern and control of primary production: Rates and patterns of primary production will be measured by ^{14}C uptake incubations on four cruises per year in our LTER site in collaboration with CalCOFI (Fig. 15). Such measurements have been made since 1984 in the CalCOFI region. In addition to *in situ* measurements, we have parameterized algorithms to estimate primary productivity (Kahru et al. 2009) from satellite remote sensing. Our investigations of controls of primary production include experimental Process studies on the effects of irradiance, N, Si, Fe limitation, and Fe-light co-limitation on phytoplankton specific growth rates. The role of grazing pressure by nano-, micro-, and meso-zooplankton, and sinking fluxes, are also addressed on Process cruises.

Spatial and temporal distribution of populations selected to represent trophic structures: We will focus on organisms representing different trophic levels as well as "sentinel species," many of which are known to provide excellent indications of responses to ecosystem changes in the CCS. These organisms will be sampled or sighted (seabirds) four times per year on the CalCOFI sampling grid, characterizing spatial as well as temporal variability. They include: **Bacteria**- heterotrophic prokaryotes (flow cytometry, Taylor et al. 2015; rRNA DNA barcoding, A. Allen, see below); **Phytoplankton**– *Procholorococcus*, *Synechococcus* (flow cytometry), phytoplankton chemo-taxonomic groups (HPLC, Goericke 2011) and rRNA DNA barcoding (de Vargas et al. 2015; see below); **Particle-feeding zooplankton-** selected species of copepods, salps and doliolids; **Omnivorous zooplankton**- selected euphausiid species;

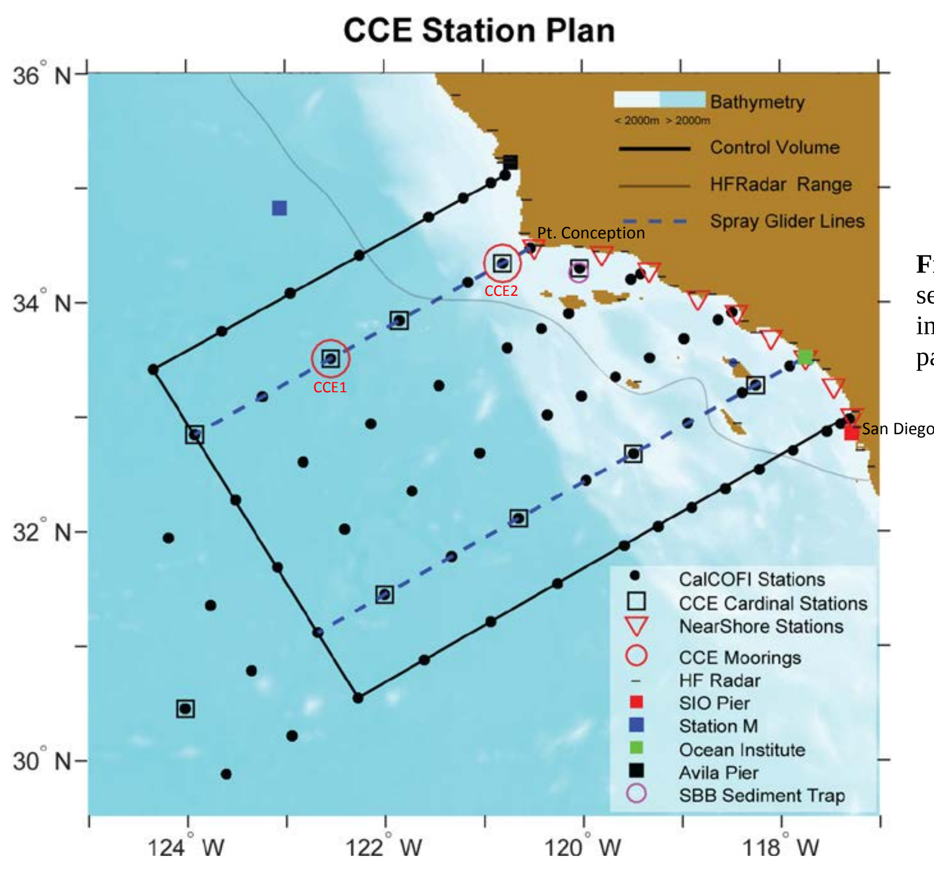

Fig. 15. CCE time series sampling plan, including many partner programs.

Carnivorous zooplankton- selected hydromedusae and siphonophores (all by microscopy, Lavaniegos and Ohman 2007); zooplankton functional groups and size classes (ZooScan, Gorsky et al. 2010, Ohman and Romagnan 2016); **Zooplanktivorous fish-** Pacific sardine, northern anchovy, and jack mackerel (Southwest Fisheries Science Center): **Seabirds-** Sooty Shearwater, Cassin's Auklet, Rhinoceros Auklet, Cook's Petrel, and Black-vented Shearwater (at-sea observers, Sydeman et al. 2015). Aggregated measures of total biomass of phytoplankton (as Chl *a* and HPLC chemo-taxonomically defined categories) and mesozooplankton (from size-based reconstruction using ZooScan, as well as displacement volume) will also be made.

A new element of our core population studies in Phase III will be the utilization of molecular tools to characterize diversity. The recently initiated CalCOFI Genomics Project (NCOG, Andy Allen, PI) is using molecular methods to characterize spatial and seasonal trends in microbial diversity (e.g., Fig. 8B) and associated plankton interactomes (Fuhrman et al. 2015, Lima-Mendez et al. 2015) in the CCE region. Allen and CCE Associate Brian Palenik will also be expanding the use of molecular methods to characterize microbial diversity on our experimental Process cruises, as described above.

Pattern and control of organic matter accumulation and decomposition in surface layers and sediments**:** Sedimentary accumulation and utilization of organic matter in the deep sea is addressed by CCE Associate K. Smith at his long-term deep-sea time series station at Sta. M (Fig. 15). Smith and co-workers characterize the time-varying flux of particulate organic carbon to sediments in the deep sea, its utilization, and consequences for the benthic macrofauna. We also analyze the coupling between the CCE epipelagic zooplankton community and fluxes of organic matter to the sea floor (e.g., Smith et al. 2014). In addition, we have a new partnership with the Santa Barbara Basin sediment trap program of R. Thunnell and C. Benitez-Nelson, permitting high-resolution quantification of fluxes of organic C and N, inorganic ballast minerals, microfossils, and other quantities in the nearshore CCE. On our experimental Process cruises, we measure the rate of organic matter export from the euphotic zone using both the ^{234}Th disequilibrium method and sediment traps (Stukel et al. 2015) and will now include J. Bishop's autonomous C Flux Exporers (Bishop et al. 2016). Cycling, transformation, and utilization of dissolved organic matter are analyzed by L. Aluwihare using diverse analytical methodologies (e.g., Meador and Aluwihare 2014, Pedler et al. 2014).

Patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters**:** Changes in concentrations and fluxes of nutrients are addressed in our time-series, experimental, and modeling studies. Time-series observations, on the quarterly augmented CalCOFI cruises, will assess long-term changes in nutrient stoichiometry (Bograd et al. 2015) as well as spatial patterns of nutrient concentrations (NO_3, NO_2, NH_4, $Si(OH)_4$, PO_4), nutricline depths, and nutrient input into the euphotic zone via upwelling and horizontal transport. Experimental Process studies assess nutrient fluxes from Thorpe scale overturn analyses (e.g., Li et al. 2012) and trace metal (especially Fe) availability and utilization (King et al. 2012, Brzezinski et al. 2015). The CCE1 and CCE2 moorings further provide high temporal resolution measurements of NO_3+NO_2, in time series that have now existed for 6-7 years. Horizontal gradients in nutrient concentrations, combined with volume transports, permit us to calculate nutrient fluxes into our study site and Ekman divergence out of the system, helping to constrain the major sources and sinks of nutrients.

Patterns and frequency of disturbances**:** We will continue to characterize disturbances on many scales, using (1) the CCE1 and CCE2 moorings in the Southern California region (Figs. 15, 16), together with *Spray* ocean gliders and continuous measurements from the Scripps pier, (2) high-frequency temperature and Chl-*a* measurements from our Education and Outreach partner, the Ocean Institute, located in Dana Point, CA, as well as Santa Barbara Basin sediment trap series, (3) satellite remote sensing measurements, including an ensemble of satellite measurements of ocean color and SST (Kahru et al. 2015), soon to include OLCI, (4) quarterly shipboard measurements of hydrographic, meteorological, plankton, and ichthyoplankton characteristics, and (5) analyses of paleoceanographic proxies to characterize longer term (~2,000 year) variability from the varved sediment record of the Santa Barbara Basin (Field et al. 2006).

Components of the CCE- LTER program

Overview

The CCE-LTER program is now comprised of five inter-related components: Experimental Process studies, Time-Series studies, Modeling, Information Management, and Education, Outreach, and Capacity Building (EOCB). We briefly introduce the first three program elements here, while Information Management and EOCB are described below in separate sections of the proposal.

Experimental Process Studies

Three CCE Process cruises are planned for the proposed funding period, each of 32 days duration during the spring-summer period of greatest cross-shore transports (see Fig. 13). The proposed timing of the cruises in 2017, 2019, and 2021 (ends of Phase III years 1, 3, and 5) will allow sufficient time for full sample and data analysis and assimilation into models between cruises. These cruises will each involve 32-34 graduate students, undergraduates, scientists, and technicians, spanning diverse disciplines (plankton ecology, experimental physiology, metagenomics, bioacoustics, seabird and mammal ecology, trace metal and organic geochemistry, biogeochemical fluxes, physical oceanography, and others). As described above, the cruises will entail: (1) north-south *Spray* glider lines to continuously quantify cross-shore fluxes, (2) site surveys with a SeaSoar and Moving Vessel Profiler to resolve subsurface hydrography, frontal gradients, and subduction, (3) detailed sampling and experimental food web process measurements while following satellite-tracked drifters with mixed-layer drogues, (4) particle export measured by ^{234}Th disequilbrium, sediment traps, and Carbon Flux Explorers (Bishop et al. 2016), and (5) seabird and marine mammal observations.

Time-Series Observations

CCE-LTER uses diverse approaches to observe the state of the ecosystem and its changes over time and space. Most core LTER measurements will be carried out in cooperation with the CalCOFI program using ships as sampling platforms. Other platforms, such as satellites, ocean gliders, instrumented moorings, a deep-sea benthic observatory, and shore/coastal stations, acquire data at higher temporal and spatial frequencies to complement the shipboard sampling (Figs. 14, 16). Please see the separate section below on "Related Research Projects." Our measurements can be characterized as (1) discrete in time (quarterly CalCOFI augmented sampling), or (2) semi-continuous (CCE1 and CCE2 moorings, *Spray* gliders along CalCOFI lines 80 and 90, satellite remote sensing, Sta. M benthic fluxes, Santa Barbara Basin sediment trap program, and nearshore observations at the Ocean Institute and moorings and piers). This approach allows us to observe at least some system variables at virtually all relevant temporal and spatial scales.

CCE Modeling Studies

CCE modeling approaches include ocean and atmosphere circulation models, ecosystem models, ocean inverse models, and Lagrangian and transport models. ***Ocean and atmospheric circulation***: The main physical circulation model is the Regional Ocean Modeling System (ROMS) (Haidvogel et al. 2008), with multiple configurations for the CCS. The primary model domain for analysis of decadal trends and inter-decadal variability spans the entire central and eastern North Pacific between 180°-110°W, 20°-62°N (Fig. 7). Surface forcings include the US National Center for Environmental Prediction (NCEP) reanalysis, the CCS regional atmospheric hindcast from the Environmental Climate Prediction Center (ECPC) at Scripps, the Comprehensive Ocean–Atmosphere Dataset (COADS), advanced very high resolution radiometer (AVHRR) data, and/or the QuikSCAT satellite scatterometer data for winds. Open boundary conditions are provided by the Japanese Earth Simulator, the high-resolution version of the Simple Ocean Data Assimilation (SODA) reanalysis (Carton and Giese 2008), and the ECMWF ocean reanalysis ORAS4 (Balmaseda et al. 2013). The large-scale model domain permits dynamical analysis of transitions between the CCS and neighboring regions as well as comparisons of ecosystem variability between regions (e.g. with the Gulf of Alaska) (Di Lorenzo et al. 2009). **CCE Model Reanalyses**: Dataassimilative historical reanalyses of the CCE (Neveu et al. 2016) will be used to investigate the scales of variability of remote and local forcing mechanisms, and their interactions with each other, to distinguish transient ecosystem impacts and ecosystem transitions from secular change (Jacox et al. 2015a,b). The reanalyses will also provide model-derived estimates of upwelling in near real time, to determine the source and properties of upwelled waters, and to provide direct estimates of upwelled nutrients, which ultimately drive productivity. ***Ecosystem***: To investigate physical-ecosystem-biogeochemical dynamics we will use the ROMS-NPZD (Powell et al. 2006, Di Lorenzo et al. 2008), including iron limitation (Fiechter et al. 2009), and a modified ROMS-NEMURO model (Kishi et al. 2007, Li et al. 2010, 2011, Taylor et al. 2015). We are currently formulating a modified NEMURO-like model to explore the dominant food web elements in the CCE, and a continuum size-structured planktonic ecosystem model (Taniguchi et al. 2014) to investigate physical-biological couplings in mesoscale features. ***Ocean Inverse Model***: The ROMS model includes an inverse modeling component that uses the Tangent Linear and Adjoint Models of the ocean circulation module (Moore et al. 2004). Several studies conducted by the PIs have used this inverse platform to explore the sensitivity of the physical and biological systems to changes in forcing conditions and upwelling in the CCS (Chhak and Di Lorenzo 2007, Veneziani et al. 2009, Moore et al. 2009). In support of CCE Process Cruises, the ROMS 4D-variational data assimilation system will be used to assimilate *in situ* temperature and salinity data from hydrography, SeaSoar observations, glider data, and ADCP upper-ocean currents, along with satellite altimetric estimates of sea level, satellite observations of SST, ocean data from the NOAA buoys, and whatever other data types are available. These fits will attempt to reconstruct the mesoscale circulation observed during cruises (e.g., Miller et al. 2015), and provide crucial dynamically consistent diagnostics of the circulation for interpreting the interactions among physical, atmospheric and biological dynamics. ***Lagrangian and Transport Models***: To characterize fluxes associated with cross-shore filaments and mesoscale eddies we will use the ROMS passive tracer (Combes et al. 2009) and Lagrangian (Petersen et al. 2009, Drake and Edwards 2009) module, as well as the Ariane particle-tracking code (Blanke and Raynaud 1997, Blanke et al. 1999). These modules have been used to characterize alongshore connectivity (Rasmussen et al. 2009), the dynamics of cross-shore exchanges and their relationship to the upwelling cells (Combes et al. 2013), and the dynamics in cyclonic eddies of the CCE (Chenillat et al. 2015a, b).

Regionalization, Cross-Site, and Collaborative Studies

Linkages to other LTER sites

CCE has a natural connection to Santa Barbara Coastal (SBC), as CCE includes sources of ocean forcing that influence their kelp forest site. We have annual exchanges with SBC and Moorea Coral Reef (MCR) graduate students and postdocs. SBC and CCE are partially co-supporting Santa Barbara Basin sediment trap studies coordinated by Claudia Benitez-Nelson (U. So. Carolina), because of our sites' common interest in this record. SBC co-PI M. Brzezinski is an active collaborator with CCE (e.g., Brzezinski et al. 2015, Krause et al. 2015), and SBC's L. Washburn is a collaborator on the CCE mooring project. A CCE graduate (Mike Stukel) completed a postdoc with Palmer Station LTER (PAL), and is currently working with both sites on export fluxes. At the LTER All-Scientists meeting in Sept. 2015, CCE and PAL met jointly and developed a plan for explicit comparative work, initially focusing on ENSO influences at our respective LTER sites. We also intend to carry out further cross-site comparative studies of ENSO impacts, and to continue work with other sites that are addressing ecological state changes. We also look forward to expanding interactions with others in the LTER network.

International collaborations

In Phase III, CCE is further developing our collaborations in France (Villefranche-sur-mer and Plouzané); with plankton ecologists and biogeochemists in China; fisheries oceanographers in Japan; and others in Mexico, Portugal, and Brazil. We see every sign of these collaborations expanding.

3. Related Research Projects

CalCOFI - The *California Cooperative Oceanic Fisheries Investigations* (CalCOFI) program provides 67 years of invaluable context measurements for CCE. CalCOFI is a consortium of NOAA Fisheries, the California Department of Fish and Wildlife, and the University of California (via Scripps), and is supported by NOAA. Our partnership with CalCOFI is fundamental to CCE, because this is the platform from which we sample most of our LTER core variables (**primary production, nutrients, population studies, organic matter recycling**), as well as their hydrographic context. There are 4 CalCOFI cruises per year, each covering a pattern of 75 stations in the CCE region (Fig. 15). In addition, two of those cruises sample 38 additional stations extending into the Central California region in winter and spring (the time of peak spawning of key clupeid fishes). A comprehensive suite of hydrographic and meteorological variables is measured at each station, to a high technical standard. CalCOFI supports sample processing, quality control, and digital posting of: CTD profiles, dissolved nutrients, O_2, Chl-*a*, primary production, Secchi depth, PAR, meteorological variables, and others. Zooplankton and ichthyoplankton have been sampled since 1949 and all samples are archived in the SIO Pelagic Invertebrates Collection. TCO_2, TAlk and pH measurements are made by the A. Dickson lab with separate funding. EK60 multi-frequency acoustic backscatter is measured to estimate biomass of small pelagic fishes and larger zooplankton.

With NSF support for CCE, we will extend CalCOFI cruises by three days each to take additional measurements and samples for “Augmented CalCOFI.” CCE augmentations include sampling for flow cytometry for heterotrophic and autotrophic picoplankton; phytoplankton community structure via taxon-specific pigments (HPLC); POC and PON; total organic C; finer mesh (202 µm) zooplankton samples for analysis by digital ZooScan (Gorsky et al. 2010, Ohman and Romagan 2016); underway sampling of pCO_2 and pH (T. Martz); and Advanced Laser Fluorometry characterization of phytoplankton pigments and variable fluorescence (Chekalyuk and Hafez 2008). In Phase III we also plan to add deep casts for DIC and TOC validation, and large volume samples for A. Allen’s metagenomic microbial network surveys. CCE also supports costs for seabird observers on CalCOFI cruises each year (W. Sydeman).

Satellite Remote Sensing - Satellite remote sensing of ocean color, sea surface temperature (SST), and sea surface height provides synoptic measurements of the entire CCE study region. The CCE remote sensing program is run by M. Kahru. The California Current System has been a test bed for developing ocean color algorithms for decades (e.g., Smith and Wilson 1981; Kahru and Mitchell 1999; Kostadinov et al. 2007), and standard NASA ocean color algorithms (O’Reilly et al. 1998) were largely parameterized with in situ measurements from the southern California Current. Recent NASA funding (PI Kahru) has produced a series of papers (e.g., Kahru et al. 2012, 2015) that have developed merged, multi-satellite datasets of bio-optical variables including Chl-*a* concentration and primary production. The 4-km merged and recalibrated datasets are available online, and the 1-km merged datasets are updated ~weekly. A new development is the launch of a European satellite with an advanced ocean color sensor (OLCI) in early 2016; Kahru is a member of the OLCI validation team. OLCI will be valuable for developing and implementing new and biologically relevant algorithms, such as those to derive the abundance of phytoplankton functional and size groups. OLCI has higher spatial resolution (300 m) and many spectral bands. Satellite remote sensing measurements contribute to our areally averaged inferred trends in the LTER core variable of **primary production rates** (e.g., Kahru et al. 2009), to analysis of changes in ocean frontal features, a primary focus for our process cruises in Phase II (e.g., Kahru et al. 2012, 2015), and to selection of specific water parcels for our process cruises (e.g., Ohman et al. 2013).

California Underwater Glider Network (CUGN) - The CUGN uses *Spray* gliders (Sherman et al. 2001, Rudnick et al. 2004, Rudnick 2016) for sustained operations along three CalCOFI lines, two of which (lines 80 off Point Conception and 90 off Dana Point) continuously sample the CCE region (Fig. 15). The CUGN started in 2005, and has been continuous on all three lines since 2009 (Davis et al. 2008, Johnston and Rudnick 2015). *Spray* samples from 0-500 m, telemetering data ashore at each surfacing, on 3-hr intervals. The present measurements are temperature, salinity, pressure, Doppler currents, acoustic backscatter (750 kHz), and Chl-*a* fluorescence. An ongoing project is to equip the gliders with dissolved O_2 sensors, for characterization of hypoxia and estimation of omega-aragonite from proxy relationships (Alin et al. 2012). The *Spray* glider data are important to CCE because they help characterize ENSO variations (Todd et al. 2011) and provide real-time assessments of physical and biological ocean conditions (e.g., Powell and Ohman 2015a) that are needed to guide site selection for our Process Cruises. The CUGN is led by Daniel Rudnick (SIO), an Associate of CCE, and is supported by NOAA. Nearly real-time CUGN data and graphical displays are available online.

CCE Interdisciplinary Moorings - Uwe Send and Mark Ohman run an interdisciplinary mooring program with two deep-water moorings that sample the core of the California Current (**CCE1**, 4,000 m depth) and the coastal upwelling region off Pt. Conception (**CCE2**, 770 m depth; Figs. 15, 16). These moorings have been in place since Nov. 2008 and Jan. 2010, respectively, and are replaced annually. The program is supported by NOAA, however NSF (via CCE) provides ship support for one mooring servicing cruise per year and has also supported purchase of some sensors (SeapHOx pH and O_2, SUNA nitrate). Data are telemetered in real time using inductive telemetry and Iridium and posted publicly. Measurements include pCO_2 in the upper ocean and atmosphere, meteorological variables, temperature and salinity, dissolved O_2, pH, aragonite saturation state by proxy (Alin et al. 2012), Doppler currents, NO_3+NO_2, Chl-*a* fluorescence and turbidity, wavelength-specific light attenuation, and 190 kHz acoustic backscatter. The moorings are co-located with CalCOFI stations (80.80 and 80.55, respectively), providing shipboard validation samples 4X y^{-1}. Ohman et al. (2013) illustrated the complementarity of mooring, glider, and shipboard data. High-frequency mooring measurements help us characterize the onset and decline of ENSO events and will help resolve cross-shore transport. They enable us to resolve upwelling events and the time variability of nutrient utilization (Martz et al. 2014) and are used in our studies of ocean acidification.

Abyssal Benthic Time Series at Sta. M - Long term abyssal benthic flux studies at Sta. M, just north of CalCOFI line 77, have been led by K. Smith (CCE Associate) at MBARI since 1989 (Fig. 15). This study of pelagic-benthic processes measures the continuous flux of particulate organic carbon (POC) through the 4000 m water column and variations in its utilization on the sea floor. Sediment traps (50 m and 600 m above the bottom) record abyssal particulate fluxes. Autonomous instruments (benthic Rover, ROV video transects, time-lapse camera tripod, and Sedimentation Event Sensor) measure sediment community oxygen consumption and visual changes in sedimentation and faunal activity. Concurrent measurements in the water column and on the sea floor examine episodic, seasonal, inter-annual and decadal changes in abyssal processes correlated with upper ocean processes. This study was previously funded by NSF, but since 2006 has been solely supported by the David and Lucile Packard Foundation. The Sta. M measurements include the LTER core variable of patterns and controls of **organic matter accumulation and decomposition**. Although we analyze these processes with sediment traps and Th in the epipelagic on our process cruises, the Sta. M time series makes continuous measurements relevant to the deep-sea benthos.

SBB Basin Sediment Traps (Claudia Benitez-Nelson) - Although not "essential" to CCE science, the Santa Barbara Basin Sediment Trap Time Series run by R. Thunnel and C. Benitez-Nelson (U. of S. Carolina) provides a 22-year flux time series. These studies permit analysis of the effects of longer-term changes in ocean acidity on calcium carbonate-modulated export fluxes (Thunell et al. 2007). They also permit quantification of the effects of long-term changes in nutrient stoichiometry (e.g, altered Si:N, Bograd et al. 2015) on opal fluxes, changes in diatom:dinoflagellate ratios (Anderson et al. 2008), and increased occurrence of toxic diatoms (*Pseudo-nitzschia*, Sekula-Wood et al. 2011). These flux studies are complementary to the paleo-reconstructions done from the Santa Barbara Basin sediments by CCE, extending 1,700 years (e.g., Field et al. 2006). Two automated sediment traps are deployed (at ~500 m and 250 m depth), collecting at ~2 week intervals in cups poisoned with sodium azide. Analyses include

POC, PON, P, carbonate, opal, lithogenic material, paleoceanographic proxies (stable isotopes, Mg/Ca, B/Ca), foraminifera and diatoms, etc.

The specific locations of the related research projects with which CCE collaborates may be found in Fig. 15 above. A conceptual illustration of some of the shipboard and complementary autonomous measurement systems we utilize in CCE (including satellite remote sensing, ocean gliders, and moorings) may be found in Fig.16. These measurements are integrated with numerical ocean models.

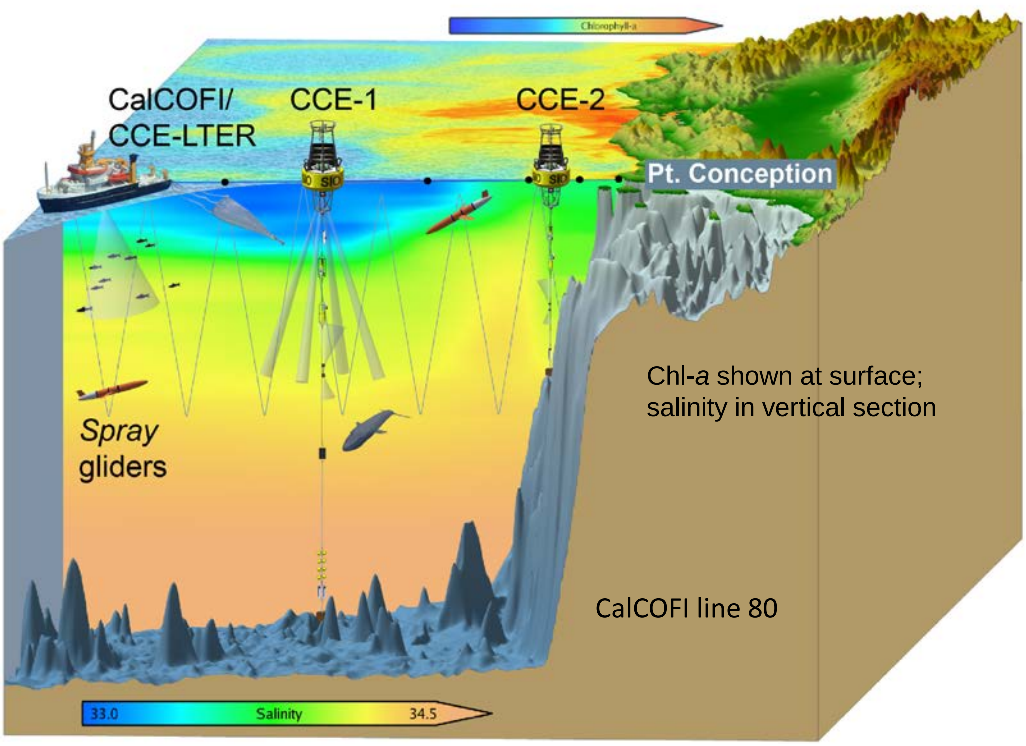

Fig. 16. Integration of shipboard with autonomous measurements and 4D ocean modeling in the CCE region (from Ohman et al. 2013).

4. Education, Outreach, and Capacity Building (EOCB) Activities

Education, Outreach, and Capacity Building (EOCB) for the California Current Ecosystem LTER provides learner-centered opportunities for K-through-gray audiences to engage with the scientific practices and data generated within this LTER site. The EOCB program at CCE has matured to include: (1) partnership with the Birch Aquarium at Scripps (BAS), a significant center of public education about the ocean environment and the public outreach center for the Scripps Institution of Oceanography; (2) collaboration with the Ocean Institute, a nonprofit educational institute located in Dana Point, CA; (3) a Research Experience for Undergraduates (REU) program each summer; (4) Research Experience for Teachers (RET) that develops teacher engagement in the Ocean Sciences; (5) participation of CCE graduate students, PhD’s, and technical staff in presentations and events for different sectors of the public; (6) direct incorporation of CCE findings into undergraduate and graduate classroom teaching and research; (7) media presentations on topical ocean issues; and (8) public access to near real-time glider, mooring, and remote sensing data and imagery. We are now adding: (9) a new alliance with a nearshore pier sampling program at Avila pier, near the northernmost extent of the CCE region, and (10) an undergraduate course in environmental film-making.

Schoolyard LTER: The successful formal collaboration between CCE and the Birch Aquarium began in 2012, when the Education Director at BAS (Kristin Evans) also became the EOCB Coordinator for CCE. Our current EOCB Coordinator is Charina Cain Layman, who also serves as the Public Programs Manager at BAS. Ms. Cain coordinates CCE programs, working in association with the Lead PI (M. Ohman), the CCE Program Office Coordinator (R. Westlake Storey), and a faculty member who directs our REU program (K. Barbeau). The collaboration between CCE and BAS leverages the Aquarium's strengths in science interpretation to reach a visitor population averaging 430,000 people per year, including audiences from diverse backgrounds. Visitors include members of the general public, school groups on organized visits, teacher groups who come for professional development training, UC San Diego and SIO students learning about science communication techniques, and others. The new aquarium director (H. Helling) has strongly endorsed interactions between BAS and CCE.

Broadening K-12 and Public Educational Activities, Phase III*:* Over the next six years we will increase the reach of the CCE-LTER site through activities that address CCE's new research initiatives while continuing to support several existing programs through the collaboration with the Birch Aquarium. The new programs will focus on the use of authentic data collected within the CCE to increase awareness among K-12 and public audiences of the role of El Niño and cross-shore transport processes in influencing ecosystem productivity.

We will deliver annual *Teacher Professional Development Workshops* focused on using authentic data in the classroom. Based on Next Generation Science Standards, post-elementary teachers will develop first-hand, inquiry-based science experiences. These CCE-based workshops will provide teachers with experience using authentic data to help students investigate real-world phenomena and will also incorporate the experience of remotely following CCE research expeditions at sea. We will leverage opportunities from Birch Aquarium programs that target teachers in a middle school program primarily for underserved students. We will focus on the effects of ocean currents and cross-shore transport on ocean ecosystems. Teachers will meet graduate students and directly experience work done in the CCE site. EOCB staff will work with CCE graduate students and researchers to develop lessons for teachers to take back to their classrooms, including developing new entries for the DRK-12 funded Data Nuggets website.

We will continue our very successful REU program, actively recruiting students from under-represented groups to participate each summer in close association with CCE mentors, other graduate students, and faculty. We work to find a close match between each mentor (usually an advanced graduate student or postdoc) and mentee. They usually meet daily, often working side-by-side. The REU's are helped to formulate a research question early on, to carry the work through to completion, then to make an oral presentation on the outcome of their research in our REU forum. In addition to designing, carrying out, and reporting on research, REUs meet together regularly at lunches to learn about other CCE projects with CCE participants. REUs lead lab tours of the lab where they work, and learn to explain their lab's activities to other REUs. In Phase II we will, in addition, conduct *Scientist Communication Workshops* for the REU students each summer. We will provide graduate student near-peer counseling on graduate applications. We will encourage REU students to attend academic lectures and sessions about careers in STEM fields. We will follow REU's career progression through post-experience surveys.

Our public events targeting learners of all ages will include: *Exploring Ocean STEM Careers Night* held each spring, where several researchers and graduate students share information about their research and career pathways with middle and high school students and their parents; *Full Moon Pier Walks* during which the general public is invited to explore a working research pier while engaging with CCE graduate students; a *SEA (Science, Exploration, and Adventure) Days* event hosted by a CCE researcher who will engage the public in hands-on activities that highlight current research; and *Think Tank: Plankton*, an activity that engages Birch Aquarium guests in CCE research regarding the seasonal changes of plankton. We will continue our popular presentations by CCE graduate students in local secondary schools.

Beginning in Fall 2017, we will begin a new partnership with California State University, San Luis Obispo (Cal Poly), led by Dr. Alexis Pasulka, a newly hired faculty member there and a CCE alum. She will initiate a Chl-*a*-temperature time series project (targeting picoplankton as well as total phytoplankton) from the Avila pier, at the northern end of the CCE domain, and will begin a metagenomics time series of nearshore planktonic organisms.

Another new part of our EOCB program will be an upper division undergraduate course offered at UCSD starting in Spring 2017, entitled *Documenting our Ocean*, TDDE 131. This course will directly link STEM undergraduate students with Arts and Humanities students. In teams of three, student groups will each produce a short documentary film based on research in CCE. Each student group will design and carry out the project from their own perspectives. Through interviews, original research, and perhaps a short research ocean cruise, students will explore methods to make CCE's scholarship engaging for a general public via documentary and animation techniques. This course will be led by Tara Knight, a filmmaker, animator, and projection designer for live performance. She is Associate Professor of Digital Media and Associate Dean for the Division of Arts and Humanities at UCSD and has extensive experience in filmmaking and teaching. This course will be closely coordinated with M. Ohman, CCE Lead PI. We will continue to work with the SIO Communications office in providing interviews with print, television, and social media on topics of interest (recently: El Niño, beach strandings of marine organisms, range expansions, climate change, plastic micro-debris).

Changes at CCE in response to mid-term site review (Sept. 2013)

The summary letter from NSF regarding CCE's mid-term review began "*The review team gave NSF an overall laudatory evaluation giving the LTER high marks in all aspects of the LTER review criteria. NSF generally concurs with their evaluation*." We provide responses to the panel and NSF suggestions below.

1. Panel comment: *Given the large spatial extent of CCE, continuing to reach out to partners outside of the LTER network is appropriate.* NSF comment: *Extend consideration of the CCE LTER into the northern areas of the California Current System.*
We have taken the following steps. CCE scientists now have explicit, cooperative science projects with colleagues from 11 institutions on the U.S. west coast, ranging from north to south: University of Washington, NOAA Pacific Marine Environmental Lab, NOAA Newport lab, UC Davis, Farallon Institute for Advanced Ecosystem Studies, UC Berkeley, UC Santa Cruz, Monterey Bay Aquarium Research Institute, NOAA Environmental Research Division, UC Santa Barbara, and NOAA Southwest Fisheries Science Center. These collaborations include at least 14 PhD scientists from these institutions. We also have collaborations with colleagues in Mexico, especially CICESE in Ensenada. Recently, CCE scientists have collaborated with colleagues from Baja California-to-Alaska in two workshops addressing *2014-2015 Pacific Anomalies*, one in La Jolla (April 2015) and one in Seattle (Jan. 2016). CCE scientists co-led a session with colleagues on "*Pacific Ocean anomalies of 2014-2015: Consequences for Marine Ecosystems*" at the Ocean Sciences Meeting in Feb. 2016. CCE is cooperating with colleagues coast-wide in a new workshop on "*Predictability of U.S. West Coast Ecosystems Based on ENSO Forecasts*" in summer 2016. Virtually all CCE scientists interact with more northern (and some more southern) colleagues, including many joint publications. At the same time, we are sure that NSF and reviewers recognize that, while our modeling and remote sensing studies often extend far to the north and the south, it is not feasible for CCE to carry out ocean measurements throughout the California Current System. The larger system-wide understanding that we all seek must be built on collaborative interactions.

2. *Consider dedicating additional resources to outreach and education* (NSF did not endorse this recommendation). The panel's comments began: "*The CCE LTER site is doing an excellent job of education, outreach, and training*" and later commented on the relatively small part of the budget devoted to E&O. The modest Schoolyard, REU, and RET supplements are the primary resources we have to support such activities. Those funds do not include our support of graduate students and postdocs, which represents a significant part of the CCE budget, nor REU match that we have received from SIO/UCSD. In addition, the newly hired Director of the Birch Aquarium at Scripps is strongly committed to furthering interactions with CCE, as explained in our Education, Outreach, and Capacity Building Activities section.

Information Management

The panel recognized CCE's "*…technologically innovative system known as the 'DataZoo'…*" and "*…a dedicated and talented team of IM specialists, strong support from site leadership, a history of innovation and leadership in LTER Network IM activities and excellent computational infrastructure*." The panel also made the following constructive suggestions:

3. *CCE researchers should include a wider array of data in their information management efforts.* Since the midterm review, CCE has added a number of different types of datasets to its catalog that now include model output, short-term projects, historical collections, and other resources, in addition to our core time series and Process Cruise updates. The CCE Information Manager more actively encourages CCE participants to submit data for all types of research.

4. *CCE should improve its system to provide "one-stop-shopping" for CCE data*. CCE's Datazoo now provides specific links to specialized data resources that are not served through Datazoo itself. We migrated our previous "Related Resources and Data" listing directly into Datazoo's searchable catalog. Entries are now keyworded using the LTER controlled vocabulary and indexed along with all other datasets, and readily accessible through Datazoo.

5. *CEE should increase its participation in LTER-wide data catalogs and repositories*. CCE has increased its submissions of datasets to the current LTER network data system, PASTA, and is close to 100% submission. We are finishing work on just a few complex cases. Metacat has been retired by the LTER network and is no longer supported. CCE also continues to contribute to ClimDB, to the LTER personnel directory, and to the bibliography.

NSF's additional suggestions included:

6. *Build interactions with both the LTER Network data system and other data systems supported by NSF Division of Ocean Sciences.* - CCE is collaborating directly with BCO-DMO and the other OCE-funded LTER site information managers. The BCO-DMO system currently displays LTER datasets from OCE-funded LTER sites by pulling from the DataOne catalog, of which the LTER PASTA system is a member node. We have worked with BCO-DMO personnel to facilitate ease-of-use and data retrievals. The CCE Information Manager, James Conners, attended the EarthCube Ecosystem Dynamics workshop in the fall of 2013 and continues to follow the cyberinfrastructure initiative's progress.

7. Plan for project management succession – Our Project Management Plan below includes an explicit succession plan.

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Facilities, Equipment and Other Resources

Personal office space is provided by UCSD to all SIO participants, and by other host institutions to respective participants.

Specialized lab equipment includes: Zeiss Axiovert 200 inverted microscope with motorized stage and Apotome Imaging workstation for automated slide processing, 3-D reconstruction and extended-field focus (Landry lab). Shimadzu TOC-V CSN with Total Nitrogen analyzer for TOC/TON, and Agilent GC-EI MS for lipid analysis (Aluwihare lab). Trace metal lab equipped with Millipore Milli-Q ultra pure water system, class 100 laminar flow benches, and all-plastic laminar flow/fume hood for working with acids. Major analytical equipment includes: 2 FeLume flow-injection analysis systems, 2 BioAnalytical Systems Epsilon Electrochemical Workstations with Controlled Growth Mercury Electrode, Jelight UVO Cleaner Model 342, Waters Breeze HPLC system with 2487 Dual Wavelength UV-Vis detector, Varian Cary 300 UV-Vis spectrophotometer (Barbeau lab). Agilent 1100 HPLC system (autosampler, pump, diode array detector, fluorescence detector, chemstation software) for the analysis of pigments and a Shimadzu spectrophotometer for calibrations (Goericke lab). ZooScan digital scanning and analysis system for digital imaging and classification of mesozooplankton samples; Nikon and Wild dissecting microscopes and Olympus epifluorescence compound microscopes; Turner 10AU fluorometers; Iatroscan Mark V; electrobalance; -80° freezers; Silicon Mechanics server with RAID array and remote backup (Ohman lab).

The Ocean Data Facility at SIO/UCSD performs dissolved nutrient analysis by autoanalyzer and maintains instruments such CTD's, Mocness, and Seasoar. The SIO Analytical Facility maintains numerous instruments, including a Costech ECS 4010 elemental analyzer with a zero blank autosampler and a Finningan Delta Plus IR/MS with gas bench for stable C and N isotope analysis, both supervised by a skilled analytical chemist. The CalCOFI technical group at SIO conducts high quality hydrographic measurements, ^{14}C liquid scintillation counting, chlorophyll analyses, dissolved oxygen titrations, etc., with careful attention to calibration and quality control and has all relevant analytical equipment. Extensive small laboratory (microscopes, refrigerated centrifuges, microbalances, dewars, etc.) and shipboard (incubators, etc.) equipment is available in support of this research. The SIO Pelagic Invertebrates Collection is a professionally maintained facility where archived plankton samples are accessioned, curated, and made available. Flow cytometric analyses will be done at the SOEST FCM facility at the University of Hawaii or the flow cytometry facility at SIO. The SIO Marine Sciences Development Shop is a fully equipped facility with automated milling machines and extensive experience in design, construction, and repair of seagoing instruments, with services available on a recharge basis.

The sequencing technologies at the J. Craig Venter Institute include: Illumina NextSeq, HiSeq 2000 and MiSeq. JCVI has an Illumina HiSeq 2000 system with the TruSeq V3 chemistry which has a capacity of 600 Gb per run or 15 Tb per year. The Illumina NextSeq quadruples this output in only 2-3 days. The Illumina sequencer is supported by the use of an Illumina cBOT Cluster Generation System. A MiSeq provides fast turnaround long-read sequencing of up to 2x250 bases in about a day. Also, within the Allen Lab, a TimeLogic DeCypher System emplying J-Series FPGA Hardware is available for high performance computing necessary for bioinformatics work. Associated software includes Tera-Blast, HMM3, and Velocimapper for efficient BLAST, annotation and read mapping (A. Allen lab).

Specialized field equipment includes: Four custom WOCE style holey sock-drogued drifters with Globalstar satellite tracking and Iridium and Argos telemetry, with attachment points for incubation bottles at 8-10 light depths (Landry lab); a free-fall Moving Vessel Profiler for continuous underway vertical profiling of upper ocean properties with Laser Optical Particle counter, CTD, Chl-*a* fluorometer, and Acousonde probe (Ohman lab); 2 moorings with pCO_2 sensors, SeapHOx, ADCP, meteorological sensors, 7-channel radiometers, SeaCat CTD, SUNA nitrate, O_2, Echotag sonars, FLTNUS Chl-*a* and turbidity, with inductive telemetry (Send and Ohman labs); *Spray* ocean gliders equipped with pumped Sea-Bird CTD, Sea Tech Chl-*a* fluorometer, Acoustic Doppler Profilers, and some with Sea-Bird optode O_2 sensors (Rudnick lab); towed SeaSoar with paired SeaBird SBE-9Plus CTDs, Seapoint SCF Chl-*a* fluorometer, Wet Labs C-Star transmissometer, Rinko-III oxygen sensor, and LOPC (SIO Ocean Data Facility); Carbon Flux Explorers with an imaging Optical Sedimentation Recorder interfaced to a CTD-equipped Sounding Oceanographic Lagrangian Observer (SOLO) float (J. Bishop lab); a 1 m^2 Mocness with 202-µm mesh nets, double 1 m^2 Mocness, and a Seasoar undulating sampler (SIO Ocean Data Facility); a 5 m^2 Oozeki trawl for larval and juvenile fish (Koslow lab); Advanced Laser Fluorescence system (A. Chekalyuk and R. Goericke lab); flow through system for pCO_2/pH/Temp/Salinity consisting of Sunburst SuperCO_2; Honeywell UDA2182; Sea-Bird 37 sensors and a common data hub (T. Martz lab); RISO beta multi-counter with low-radioactivity lead shielding, access to inductively-coupled plasma mass spectrometry to be used for determining the $^{229:230}$Th isotopic ratio for ^{234}Th yield analyses (M. Stukel lab at FSU); for trace metal clean sampling and incubation set-up four 12 liter and two 30 liter GO-Flo bottles with Teflon messengers for use on hydroline; 12-place Seabird rosette frame with CTD, pressure sensor and auto-fire module and teflon coated X-Niskin water samplers from Ocean Test Equipment; 1500 meters of hydroline for rosette or GO Flo deployment; metered block with composite sheave; all-Teflon air-driven diaphragm pump for surface water collection, several portable laminar flow units (Barbeau lab).

Computing Infrastructure
The Information Management (IM) component of the CCE LTER project is located at Scripps Institution of Oceanography, occupying office space in Sverdrup Hall. IT support is provided by the Scripps Institution of Oceanography Information Technology (SIO IT) group. SIO IT provides free basic IT support for all researchers, students and staff at SIO, including desktop, server, printing and software support services. More substantial IT services are provided on a recharge basis. A portion of IM budget is allocated for additional system administrations services for our single server machine, with a direct attached storage appliance, that runs a hypervisor with three virtual machines for: development (web, software, and database), production (web, software) and data (production database, file-sharing), in addition to development and planning consulting. All server hardware resides in the newly developed SIO Co-Location Facility equipped with backup emergency services (power, chilling, etc.) and environment and security monitoring. Data backup services are also provided by SIO IT, including high frequency snapshots and offsite redundancy for disaster recovery.

All IM personnel are currently provided with iMac 7,1 machines, with additional machines (laptops) available for collaborative work or as backups. Shared printers, fax machines, copiers and other office facilities are also available within the building. The CCE participants' groups at SIO, Georgia Tech, and UCSC have suites of small multi-processor PCs and Macs for running ocean model simulations and analyses. CCE participants also receive allocations on the computers at the National Center for Atmospheric Research.

Education and Outreach: The two main partners – the Birch Aquarium at Scripps and the Ocean Institute – each have facilities to accommodate and teach tens to hundreds of visiting students at a time, and have extensive experience in program development to serve K-12 students. The Ocean Institute's vessel, R/V *Sea Explorer*, is equipped with a SeaBird CTD/rosette system and CCE has provided them with a Turner Designs fluorometer for analysis of chlorophyll samples. CCE technical staff calibrate the fluorometer on a regular basis.

Full office and support staff are provided by the Integrative Oceanography Division Business Services office to aid in the management of this and other funded projects.

CCE Process Cruise multi-disciplinary studies will be performed on the R/V *Roger Revelle* (or equivalent vessel) with capabilities for a minimum of 34 people in the science party. The R/V *Sally Ride* (or equivalent vessel) will be utilized for two of the CCE-augmented CalCOFI cruises per year as well as the CCE mooring servicing cruises. These vessels are operated by SIO on behalf of the UNOLS community.

In-kind Support: SIO/UCSD will contribute extensive in-kind support toward the California Current Ecosystem Long Term Ecological Research Project, as it did during Phase II. We are not permitted to quantify this information in this proposal, but this support comes in several forms: (1) Institutional salary support for CCE-LTER co-PI's and Associates, (2) fellowship, tuition, and travel/research assistance for SIO doctoral students who are working on the CCE-LTER project, (3) support for summer REU students from all three Research Sections at SIO (Biology, Oceans and Atmospheres, and Earth), (4) UC Ship Funds support that permits graduate students to conduct independent research activities at sea in the California Current region, (5) support for the SIO Oceanographic Collections, and (6) access to extensive research facilities, specialized facilities, and computational infrastructure. There is substantial long-term commitment of SIO/UCSD in support of the CCE-LTER site.

Data Management Plan

Overview. CCE-LTER Information Management (IM) continues to be integral to the site's research, teaching, and broader communication and outreach. CCE-IM is directed by James Conners, a professional data systems analyst. Until recently he was assisted by a programmer analyst, but we are now transitioning to a model where he is assisted by one or two undergraduate assistants (as recommended by our mid-term site review panel). The CCE-IM group provides core data and information management services. It also supports various scientific, outreach, and LTER network needs through the continued development of a comprehensive information management environment.

Infrastructure and Administration. In addition to the Information Manager and assistants, a portion of the IM budget is allocated for Information Technology (IT) services provided by the Scripps Institution of Oceanography IT (SIO IT) group, formerly the CIS (Computational Infrastructure Support) facility. SIO IT provides basic system administrations services for our single server machine that runs a hypervisor with three virtual machines for: development (web, software, and database), production (web, software) and data (production database, file-sharing). During the last grant period we purchased, with supplemental funds, a new direct attached storage unit (Dell PowerVault) that increased our potential storage capacity to ~100Tb. Both our physical server and storage unit reside in the newly developed SIO Co-Location Facility equipped with backup emergency services (power, chilling, etc.) and environment and security monitoring. Data backup services are also provided by SIO IT, including high frequency snapshots and offsite redundancy for disaster recovery. In addition to these services, SIO IT provides invaluable consultation and guidance (server configuration, security, application development, technology trends/standards, etc.) through its long-time relationship with CCE-IM. James Conners also serves on the SIO Computing Committee (2011 – present), which advises the SIO Director on computing technology matters pertinent to research and staff at the institution.

Website. The project website for CCE-LTER was re-developed in the summer of 2013, supported by supplemental funds, using Drupal CMS. This software was chosen after careful research into current website management platforms and after reviewing the potential benefits of sharing a common website framework technology among a growing number of other LTER sites. With this redevelopment, we saw improvements in content management, productivity, and organization, as well as better security maintenance. The project website is integrated with our personnel and bibliographic databases through custom Drupal modules, and incorporates the project Flickr and YouTube accounts for sharing multimedia. CCE will continue to conduct regular community reviews of its project website in order to assess and improve such aspects as usability, look-and-feel, and the organization and availability of pertinent project information. In Phase III, we plan to better utilize our relationship with the Birch Aquarium at Scripps (through CCE's EOCB program) in order to improve aspects of the website through their experience interfacing with the broader public.

Data Availability. The primary data access and catalog system for CCE is Datazoo. Built using open source technology (MySQL, PHP, Apache, JavaScript) Datazoo provides an integrated data access and documentation system for all of CCE's core data. Datazoo's relational model supports the current LTER standards and best practices and integrates the LTER Controlled Vocabulary and Unit Registry NIS (Network Information System) components to support standardized search terms and scientific units across network sites. Datasets from Datazoo are currently being published to the LTER network archive (PASTA) using Ecological Metadata Language (EML 2.1.1) At the time of writing, 100% of datasets (not including associated data listings) in the CCE LTER catalog are published in the LTER network archive (see Appendix, Dataset Table). The majority of CCE datasets are time series and are composed of data from multiple research sampling expeditions. The datasets from CCE currently in PASTA represent approximately 382 data products from roughly 93 individual sampling efforts, not including the CalCOFI hydrographic time series, which nearly triples these numbers.

Recently, Datazoo was updated to accommodate non-tabular data entities, varying numbers of data tables per datasets and also catalog entries for data resources not produced by CCE but relevant to site research and regularly utilized by the community. These updates now provide 'one-stop shopping' for CCE data. CCE also conducts regular reviews of its primary data system catalog in order to facilitate efficient access to site data by local researchers and the broader community through an intuitive interface.

Datazoo supports finding datasets via queries utilizing full-text indexing and weighting across a number of metadata elements, in addition to an intuitive faceted search interface that supports project-specific categories for data organization. Datasets can be queried, previewed, plotted and downloaded (CSV, Excel) through Datazoo's interface. Both the data querying and data plotting functions of Datazoo were built as modular system components that support generalized offline processing for producing large data results and a variety of plots.

Since the midterm site review, CCE has added a number of datasets to its catalog that include data from model output, short-term projects, historical collections and other resources, in addition to our core time series updates. Also, more effort has been made within the project to educate both long-term and new community members on the importance of timely data submission, including a wider variety of research products.

In addition to Datazoo, CCE-Information Management has developed and currently maintains a number of additional data system application components that provide access to unique data collections that support specific research objectives. FileFinder is an application for indexing large and more complex file collections and provides an interface for searching, packaging and downloading data. FileFinder permits access to CCE's processed Moving Vessel Profiler (MVP) data. In addition, the Cooperative Zooplankton Dataspace is home to two applications for querying, plotting and downloading data from two extensive zooplankton and euphausiid collections, ZooDB and the Brinton and Townsend Euphausiid Database (BTEDB), in addition to the SIO Pelagic Invertebrates Collection and other resources pertinent to marine zooplankton.

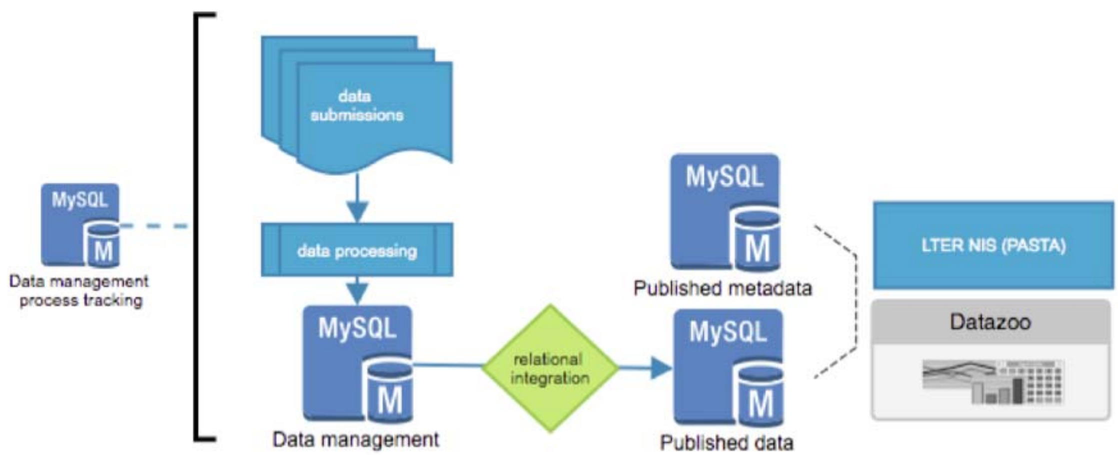
CCE-IM also continues to support outreach activities in collaboration with the Ocean Institute by providing hosting, maintenance and upgrades to their data collection application, originally developed by CCE-IM in 2008/2009. This application provides data entry, export and plotting capabilities to facilitate the project's chlorophyll time series education program.

As a collaborative research partner with CalCOFI (the *California Cooperative Oceanic Fisheries Investigations*) at SIO, CCE-IM works closely with data managers from this group to coordinate management and availability of data, including the development of standardized database key indexes and data and record-match quality feedback. The majority of CalCOFI data is available from their website and data systems although some data products are published through the CCE's Datazoo, when this duplication improves data access, availability or coherency. In Phase III, we plan to work even closer with CalCOFI data management as we develop a more reliable, long-term solution to data integration across our groups.

In Phase III, we also plan to provide data management links for our project's new research efforts in metabarcoding. All transcriptomic and rDNA metabarcoding datasets will be stored by Associate A. Allen within the J. Craig Venter Institute (JCVI) storage infrastructure which consists of over 500 TB of highly-available storage arrays provided by EMC, NetApp, Isilon, and Dell fiber-channel storage area network and network-attached storage systems. JCVI backs up all critical data nightly through incremental backups and weekly through complete backups. The tapes of the backup procedures are stored off-site. All data will be further deposited in the public NCBI short read archive. Links to such storage records will be available at BCO-DMO and maintained on the CCE webpage.

Since the 2013 LTER ASM, CCE-IM has continued to collaborate with BCO-DMO and other OCE-funded LTER site information managers in replicating data access across the LTER and BCO-DMO data systems. The BCO-DMO system currently displays datasets from OCE-funded LTER sites by pulling from the DataOne catalog, of which the LTER network data system, PASTA, is a member node. Going into Phase III, we will continue collaborative efforts with the group in order to carry out improvements, already scoped, in order to better facilitate ease-of-use and queries (on PI, keywords, etc.).

Developments and Milestones. During Phase II, Information Management at CCE has focused on developments that ensure long-term, stable data management, productive workflows, and facilitate timely access to quality data. In addition to a new project website and added disk storage mentioned above, we re-developed our primary data management structure with the help of supplemental funds in 2013/14 that were used to hire additional personnel for twelve months. A set of standardized file formats and directory structures were created to support a more uniform data submission and publishing workflow, along with various data processing and uploading scripts and a high-level database for dataset maintenance process tracking and personnel activity coordination (DM Fig. 1).



DM Fig. 1 - Redeveloped data management workflow

Many improvements from this re-development have already been achieved, including stricter data integrity controls, more efficient data submission-to-publish timeframes, and capabilities for tracking data error origins.

CCE IM has also worked on creating documentation for its system to support long-term stability through personnel fluctuations and turnover. Confluence has been used to centralize data management process and system infrastructure documentation. In addition, all of CCE's data system applications have been migrated out of a local SVN version control system to a BitBucket account, which better supports developer coordination, issue tracking, and account management.

CCE revised its data catalog in 2013 to accommodate the then-newly released "Essential features of LTER EML data packages to improve discoverability and access" and has since continued to work towards improving dataset metadata. In 2014 an internal review was conducted that solicited feedback from CCE graduate students, PIs, and Associates about dataset metadata from CCE's entire catalog. The reviews were collated and organized and are being used to revise published site metadata. Recently, Information Management began using Cognito Forms to create data submission forms for documenting datasets. This has allowed rapid form development, deployment and fine-tuning, and provides a feature set that allows unlimited editing of submitted forms, exporting, website-integration, logic branching, and other capabilities.

In Phase III, the developments described will enable CCE IM to process data submissions more efficiently with improved quality and will make data publicly available in a shorter time-frame. Going into Phase III, we are shifting our focus towards improving the process from the scientists' end, providing services and documentation to facilitate easier submission of data and metadata.

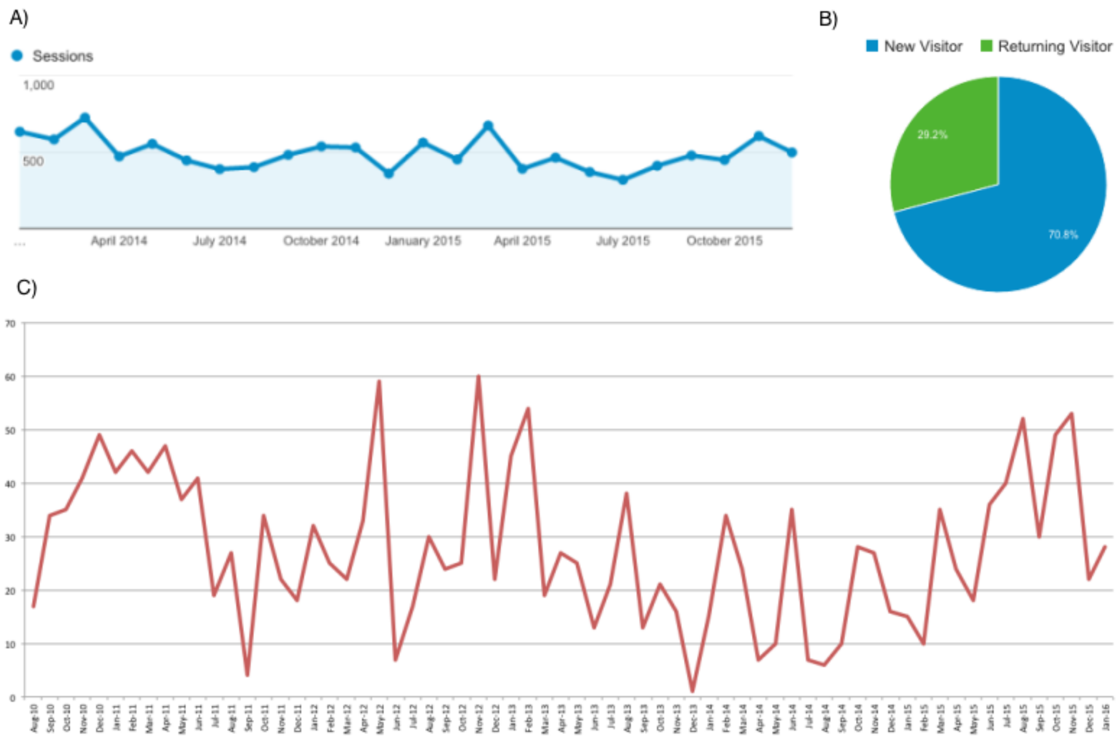
Site Science Integration and LTER Network Participation. CCE-LTER supports integration of Information Management into site science. The Information Manager is a member of CCE's Executive Committee, attending regular meetings with site PIs, students, and the Education, Outreach, and Capacity Building coordinator. In addition, the Information Manager meets regularly with the Lead PI to discuss ongoing projects, priorities, and other issues. Project leadership is supportive of Information Management initiatives and is key in coordinating efforts such as data system and website reviews as well as the metadata review survey mentioned earlier.

CCE supports network best practices through implementation of the most recent version of EML, dataset publication to the LTER network information system catalog (PASTA), and regular contributions of data to the network climate database, ClimDB. In addition, the current Information Manager, James Conners (2011-present) has and continues to participate in network-level IM. His previous activities include co-development of the Unit Registry NIS component, participation in NIS Tiger Teams and IM working groups (*Website, Web Services, Unit)*, and articles contributed to the IM newsletter, *Databits*. Conners is also a current member of the LTER Information Management Executive Committee (2013 – present). Conners also attended the *EarthCube Ecosystem Dynamics* workshop in the fall of 2013 and continues to follow the cyberinfrastructure initiative's progress.

Resource Use. CCE-LTER maintains access logs for both data and the project website in order to assess both internal and external usage of site resources. This information is presented during site meetings and serves as an invaluable tool for communication to the research community how their products are being utilized by the broader community, and for providing encouragement for improved metadata documentation and engagement.

The maps shown above in Fig. 3 of the Project Description illustrate how broadly distributed (i.e., essentially worldwide) access has been to both our website and data products during Phase II. Analytics for the most recent two years (January 2014 to January 2016) show that there have been ~12,000 user sessions with our website from ~8,500 individuals (**DM Fig. 2A**). From our records we are able to see that the current version of our website (released 2013) is doing exceeding well in drawing visitors with a very high percentage (~ 70%) of those being new (**DM Fig. 2B**). Further work is required to compare these numbers to previous years, due to variations in consistency of tracking criteria, although these numbers provide a valuable benchmark as we continue into Phase III.

Through Datazoo during the entire Phase II, there have been ~1,828 "dataset interactions" (view, plot, download, **DM Fig. 2C**) with ~38% of those resulting in downloads of the data. 98% of users provided their intended use for accessing the data. The breakdown is as follows, approximately: 90% "Academic Research", 4% Education, 3% Government Agency, 1.5% Non-profit and 1.5% Other. Dataset interactions are defined as the unique combination of an IP address, day and dataset; all IM personnel interactions are excluded from the logs before analysis of usage.



A) Website sessions per month (Jan '14 - Jan '16)
B) Website new vs. returning visitors (Jan '14 - Jan '16)
C) Datazoo "dataset interactions" per month (Phase II)

DM Fig. 2 - Website and data system activity overview

Developments and Planning for CCE Phase III. In summary, we plan to continue managing data and information in Phase III with a focus centered on long-term quality and stability, while accommodating the changing needs and requirements of LTER data management at both the site and network levels. In addition to specifics provided in previous sections, the following provides an overview of our current plans and priorities for continued work in Phase III, as developed collaboratively between Information Management and site researchers: **A)** Use community feedback and engagement to improve resources available to site scientists and students, and assist in data submissions and documentation; **B)** Develop expanded capabilities for extracting synthesized/integrated site data across different program components and investigators. At present, datasets across research components are retrievable individually, with only a select group (temporal, spatial) of sampling-integrated fields. Many investigators seek the ability to retrieve multiple, integrated datasets through single queries. This capability will be implemented through database infrastructure development and the adoption and development of best practices and standards from the LTER network and broader field of data management in coordination with collaborating projects; and **C)** Implement improved pre- and post-data collection coordination and workflow, by coordinating with individual PIs prior to data collection, in order to shorten the time frame for data submission and improve metadata documentation and consistency across all site projects.

Postdoctoral Mentoring, CCE-LTER

One postdoctoral scholar (PDS) will be funded through this CCE-LTER project. The postdoctoral researcher's development will be enhanced through a program of structured mentoring activities. The goal of the mentoring program will be to provide the skills, knowledge and experience to prepare the postdoctoral researcher to excel in his/her career path. The mentoring plan will enhance the postdoctoral experience by including career planning assistance, and opportunities to learn and employ important career skills such as writing grant proposals, teaching students, writing articles for publication, and communication skills. Specific elements of the mentoring plan will include:

- Frequent one-on-one meetings with the PI, and participation in weekly lab meetings.
- The PI will make the PDS aware of and encourage her/his participation in professional development activities – seminars, workshops, courses and events – offered by UC San Diego's Office of Postdoctoral Scholar Affairs, Center for Teaching Development, Research Ethics Program, and Career Services Center. These campus organizations provide extensive training opportunities in research skill-development, communication, scientific and public presentation, teaching, grant writing, responsible conduct of research, project management, and job search strategies.
- The PI will ensure that the PDS gains experience in both scientific manuscript preparation as well as research proposal development, including budget preparation. The PI will provide editorial as well as technical guidance. Both PDS and PI will draw on the resources available through the UCSD Office of Research Affairs' Grant Writer's Toolbox.
- The PDS will have opportunities to gain teaching, presentation and outreach experience. S/he will give a classroom lecture in a PI's graduate course, such as Biological Oceanography, Physical-Biological Interactions, Zooplankton Diversity, as well as present an academic seminar in the Ecology Luncheon seminar series.
- In the interest of developing his/her supervisory and mentoring skills, the PDS will be given opportunities to assist in the supervision of a PI's graduate students.
- On an ongoing basis, the PI will inform the PDS of in-person and on-line networking opportunities. Such opportunities are available locally through the UCSD Postdoctoral Association, and nationally through the National Postdoctoral Association. In addition, the nonprofit MentorNet offers web-based discussion groups on topics such as work/life balance, job-hunting, and diversity. UCSD is among more than 100 MentorNet campus-participants.
- The PDS will have opportunities to network with visiting scholars who are leaders in our field by having lunch or dinner with them when they participate in the department's visiting speaker series.
- The PDS will travel to national/international conferences such as ASLO and Ocean Sciences, and present a poster or paper at the conference. The PDS will also participate in the triennial LTER All Scientists meetings, and local CCE-LTER meetings and workshops. The PI will use these opportunities to introduce the PDS to colleagues and potential employers.
- The PI will help the PDS secure and make a successful transition to independent, academic employment. Drawing on his own experiences as well as community guidance and resources such as The Chronicle of Higher Education's Chronicle Forums on careers, or the Career Resources page of the Dissertation Initiative for the Advancement of Climate Change Research, the PI will help the PDS prepare for job interviews and seminars, evaluate potential academic positions, and negotiate start-up packages.

Success of this mentoring plan will be assessed by tracking the progress of the PDS through her/his Individual Development Plan, interviews of the PDS to assess satisfaction with the mentoring program, and tracking of the PDS's progress toward his/her career goals after finishing the postdoc.

SUPPLEMENTARY DOCUMENTS: DATA SETS TABLE

CCE LTER datasets in the LTER Network Information System (PASTA) as of January 2016. Configured primarily as combined time series data packages, the data products listed below comprise roughly 382 data products from approximately 93 individual sampling efforts, not including the CalCOFI hydrographic data.

LTER PACKAGE ID	CCE ID	TITLE	CORE AREA
knb-lter-cce.9	9	Conductivity Temperature Depth (CTD) Log of CTD casts from CCE LTER process cruises in the CCE region, 2006 - 2014 (ongoing).	
knb-lter-cce.10	10	Parameters from discrete bottle samples on a hydrographic CTD (Conductivity Temperature Depth) cast during CCE LTER process cruises in the CCE region, 2006 - 2014 (ongoing).	
knb-lter-cce.11	11	Chlorophyll and phaeopigments measured from discrete bottle samples from CCE LTER process cruises in the California Current System, determined by extraction and bench fluorometry, 2006 - 2014 (ongoing).	
knb-lter-cce.13	13	Daily weather summaries (temperature, precipitation and wind) for station SAN DIEGO LINDBERGH FIELD, CA US (GHCND:USW00023188), obtained from NOAA National Climatic Data Center and re-published through CCE LTER data system for community use as regionally relevant data, 1939 - 2015 (ongoing).	Disturbance Patterns
knb-lter-cce.15	15	Daily sea-surface temperature measurements, collected and provided by the Shore Stations Program, La Jolla CA, 1916 - 2015/10 (ongoing).	Disturbance Patterns
knb-lter-cce.17	17	Cruise measurements (temperature, salinity, density, chlorophyll, C14, phosphate, silicate, nitrate, nitrite) collected from CTD casts aboard CalCOFI cruises in the California Current, and averaged annually and by cruise, from 1984 - 2015 (updated periodically).	Inorganic Nutrients; Primary Production
knb-lter-cce.19	19	Final chlorophyll and temperature measurements at 10m depth, offshore of Dana Point, California as part of an Ocean Institute time series, 2006 - 2013 (ongoing).	
knb-lter-cce.20	20	Total dissolved organic carbon and nitrogen measurements at selected depths in the water column from CCE LTER process cruises in the California Current System, 2006 and 2007 (ongoing).	Organic Matter
knb-lter-cce.21	21	Measurements of dissolved inorganic concentrations of nutrient iron and of iron limitation at selected stations and depths from CalCOFI cruises in the California Current System, Nov. 2002 - July 2004 (completed)	Inorganic Nutrients

knb-lter-cce.22	22	Dissolved inorganic nutrients from CCE LTER process cruises, including 5 macro nutrients from water column bottle sample, 2006 - 2014 (ongoing).	Inorganic Nutrients
knb-lter-cce.23	23	CCE LTER process cruise, in the California Current region, event log records including date, time, position and activity for use in post-cruise data integration based on co-sampling indexes, 2006 - 2014 (ongoing).	
knb-lter-cce.54	54	Particulate organic carbon and nitrogen measurements at selected depths in the water column from CalCOFI-CCE Augmented cruises in the California Current System, 2004 - 2013 (ongoing).	Organic Matter
knb-lter-cce.55	55	Picophytoplankton and bacteria abundances analyzed with flow cytometry (FCM) from CCE LTER process cruises the California Current region, 2006 - 2014 (ongoing).	Population Studies
knb-lter-cce.57	57	Size group (pico, nano, micro) and group total carbon estimates from cell counts via epifluorescent microscopy (EPI) of heterotrophic and autotrophic plankton from CCE-CalCOFI Augmented cruises in the California Current System, 2004 - 2011 (ongoing).	Population Studies
knb-lter-cce.58	58	Cell counts (per liter) by size groups of diatoms, autotrophic and heterotrophic plankton, via epifluorescent microscopy (EPI) from CCE-CalCOFI Augmented cruises in the California Current System, 2004 - 2011 (ongoing).	Population Studies
knb-lter-cce.59	59	Conductivity Temperature Depth (CTD) sensor profile data binned by depth from stations within the CCE region from CCE LTER process cruises, 2006 - 2014 (ongoing).	
knb-lter-cce.60	60	Integrated daily photosynthetically active radiation (PAR) measured aboard CCE LTER process cruises in the California current, 2006, 2007 and 2008.	
knb-lter-cce.61	61	Photosynthetically active radiation (PAR) at depths from 0 to 100 meters, expressed as percentage of surface PAR, measured aboard CCE LTER process cruises in the California current, 2006, 2007 and 2008.	
knb-lter-cce.62	62	Exported particulate carbon and nitrogen measurements from 4-day sediment trap deployments in the CCE region, 2007 - 2012 (ongoing).	Organic Matter
knb-lter-cce.63	63	N-S and E-W components of the current (averaged by cruise cycle) as measured by a shipboard Acoustic Doppler Current Profiler (ADCP) aboard the CCE LTER process cruise in the California Current region, 2007.	
knb-lter-cce.71	71	Primary production estimates from 14C uptake (in situ), determined by the incorporation of inorganic carbon into particulate organic carbon (POC) due to photosynthesis at selected light levels from CCE LTER process cruises in the California Current System, 2006 - 2014 (ongoing).	Primary Production
knb-lter-cce.72	72	High Performance Liquid Chromatography (HPLC) pigment analysis from rosette bottle samples at various depths from CCE LTER process cruises in the California Current System, 2006 and 2008 (ongoing).	Population Studies

knb-lter-cce.76	76	Picophytoplankton and bacteria total carbon estimates from cell counts analyzed with flow cytometry (FCM) from CCE LTER process cruises in the California Current region, 2006 - 2014 (ongoing).	Population Studies
knb-lter-cce.78	78	Measurements from CalCOFI cruises in the California Current System, including log of station information, weather, sea conditions as well as physical, chemical and biological measurements including including temperature, salinity, oxygen, density, sigma theta, phosphate, silicate, nitrite, nitrate, ammonia, chlorophyll a, integrated chlorophyll a, primary productivity, and integrated primary production. 1949 - 2015	Inorganic Nutrients
knb-lter-cce.104	104	Particulate organic carbon and nitrogen measurements at selected depths in the water column in the CCE region since 2006 - 2012 (ongoing).	Organic Matter
knb-lter-cce.113	113	Size fractionation for total Chl a within the surface layer and calculated size distribution of total Chl a from discrete bottle samples from CCE-CalCOFI Augmented Cruises in the California Current System, 2004 - 2010 (ongoing).	
knb-lter-cce.119	119	Size fractionation for total Chl a within the surface layer and calculated size distribution of total Chl a from discrete bottle samples collected during CCE LTER process cruises in the CCE region, 2006 - 2014 (ongoing).	
knb-lter-cce.143	143	Assembled file of one minute averages for high resolution surface meteorological (Met) and sea water intake (SWI) data from continuous underway measurements from CCE LTER process cruises in the CCE region, 2006 - 2014 (ongoing).	
knb-lter-cce.152	152	Mean annual Secchi depth measurements in the period starting in 1969 provide a measure of water column transparency in the CalCOFI inshore and offshore areas, 1969 - 2004.	
knb-lter-cce.153	153	Monthly average of sea level measurements from San Diego Harbor, the sea level average seasonal cycle, and the long term trend are presented, 1906 - 2015 (ongoing).	Disturbance Patterns
knb-lter-cce.155	155	Assembled file of spring annual averages of abundance of selected euphausiids from the Southern California region, 1951 - 2013.	Population Studies
knb-lter-cce.159	159	Picophytoplankton and bacteria abundances analyzed with flow cytometry (FCM) from CCE-CalCOFI Augmented cruises in the California Current System, 2004 - 2012 (ongoing).	Population Studies
knb-lter-cce.162	162	Seasonal seabird density and richness of seabirds off Southern California from sampling aboard California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises, 1987 - 2006.	Population Studies
knb-lter-cce.164	164	Seasonal seabird density by species and seasonal density anomaly for four seabird species off Southern California from from sampling aboard California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises, 1987 - 2006.	Population Studies

knb-lter-cce.170	170	Assembled file of spring annual averages of measures of total mesozooplankton organic biomass as carbon, in the California Current System, 1951 - 2013.	Population Studies
knb-lter-cce.171	171	Assembled file of spring annual averages of pelagic tunicate organic biomass as carbon from the Southern California region, 1951 - 2013.	Population Studies
knb-lter-cce.172	172	Assembled file of spring annual averages of abundance of five species of cool regime salps from the Southern California region, 1951 - 2013.	Population Studies
knb-lter-cce.176	176	Water column primary production per day integrated over the euphotic zone from CCE LTER process cruises in the California Current System, 2006 - 2014 (ongoing).	Primary Production
knb-lter-cce.179	179	Cell counts (per liter) by size groups of diatoms, autotrophic and heterotrophic plankton, via epifluorescent microscopy (EPI) from CCE LTER process cruises in the California Current region, 2006 - 2008 (ongoing).	Population Studies
knb-lter-cce.180	180	Size group (pico, nano, micro) and group total carbon estimates from cell counts via epifluorescent microscopy (EPI) of heterotrophic and autotrophic plankton from CCE LTER process cruises in the California Current region, 2006 - 2008 (ongoing).	Population Studies
knb-lter-cce.181	181	Measurements, from CCE LTER process cruises in the California Current region, of dissolved inorganic concentrations of nutrient iron and of iron limitation at selected stations and depths, 2006 - 2012 (ongoing).	Inorganic Nutrients
knb-lter-cce.188	188	Data pertaining to lobster phyllosoma, Panulirus interruptus, collection methods, locations, identification and staging (1951-2008, months of July and August)	Population Studies
knb-lter-cce.194	194	Picophytoplankton and bacteria total carbon estimates from cell counts analyzed with flow cytometry (FCM) from CCE-CalCOFI Augmented cruises in the California Current System, 2004 - 2012 (ongoing).	Population Studies
knb-lter-cce.213	213	Numerical and mass concentrations of microplastic debris collected by manta net; Numerical concentrations of Halobates sericeus adults/juveniles and eggs; zooplankton biomass concentration. Various cruises from 1972 - 2010 (completed).	
knb-lter-cce.216	216	Numerical (No m-3) concentrations (mg m-3) of subsurface microplastic debris collected by bongo net aboard the Scripps Environmental Accumulation of Plastic Expedition (SEAPLEX) cruise, August 2009.	
knb-lter-cce.217	217	Feret diameter (mm), area (mm2), and circularity of microplastic debris collected by manta net aboard the Scripps Environmental Accumulation of Plastic Expedition (SEAPLEX) cruise, August 2009, and NOAA Okeanos Explorer expedition, 2010.	
knb-lter-cce.218	218	Microplastic measurements including, mass, color, particle type and plastic type collected aboard the Scripps Environmental Accumulation of Plastic Expedition (SEAPLEX) cruise, August 2009.	

knb-lter-cce.222	222	Total Thorium-234 (Th-234) taken from discrete water column samples collected during CCE Process Cruises (2006 - 2012).	Organic Matter
knb-lter-cce.240	240	Biogenic silica standing stock and its rate of production and export in the offshore Southern California Current Ecosystem, June 2011.	Inorganic Nutrients
knb-lter-cce.249	249	Size fractionation of total Chl a larger and smaller than 8 µm data generated by Mike Mullin of the Marine Life Research Group, aboard CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruises of the coast of California, January 1994 - October 1996.	
to be published	251	This data set is six 30-day ocean state estimation products for LTER-CCE cruises. The time periods of data assimilation fits for each LTER-CCE cruise are the following: 2006: 5/8 - 6/6, 2007: 4/1- 4/30, 2008 : 10/1 - 10/30, 2009 : 4/15 - 5/14, 2011 : 6/17 - 7/16, 2012 : 7/27 - 8/25	
knb-lter-cce.254	254	Temporal and spatial changes in the abundance and species composition of phytoplankton in the California Current from samples collected aboard CalCOFI cruises between summer 1996 and spring 2012.	Population Studies
knb-lter-cce.255	255	Bird and mammal observations aboard CalCOFI (1987-2015, ongoing), NMFS (1996-2015, ongoing) and CPR (2003-2006, completed) cruises.	Population Studies
knb-lter-cce.263	263	Chlorophyll and phaeopigments measured from discrete bottle samples from CCE LTER P0904 student cruise in the California Current System, determined by extraction and bench fluorometry, April 2009.	
knb-lter-cce.264	264	Parameters from discrete bottle samples on a hydrographic CTD (Conductivity Temperature Depth) cast during CCE LTER P0904 student cruise, April 2009.	
knb-lter-cce.265	265	Conductivity Temperature Depth (CTD) sensor profile data binned by depth from stations within the CCE region from CCE LTER P0904 student cruise, April 2009.	
knb-lter-cce.262	262	Index of visual monitoring, location, species behavior, and identification of cetaceans from CalCOFI cruises in the California Current System, 2005-2015 (ongoing).	Population Studies
knb-lter-cce.183		Index of visual monitoring efforts, weather conditions and position updates from CalCOFI cruises in the California Current System, 2008 – ongoing **(REPLACED BY #262)**	
knb-lter-cce.184		Index of visual monitoring, location, species behavior, and identification from CalCOFI cruises in the California Current System, 2008 – ongoing **(REPLACED BY #262)**	
knb-lter-cce.14		Average monthly weather summaries (air temperature and precipitation) at airport Lindbergh Field, San Diego, CA, 1850 - 2013.	Disturbance Patterns

Project Management Plan

Participation in the CCE site, and site management

The CCE-LTER site is based at the Scripps Institution of Oceanography, University of California, San Diego (SIO/UCSD). Ten additional institutions are represented as regular participants (see **PM Table 1**). Currently, 27 scientists or educators are involved in the site as either co-PI's or Associates, 18 of whom are located at SIO (**PM Table 1**). Internally we define a co-PI differently than NSF, which limits co-PI status to five individuals. A co-PI, by our definition, is someone for whom the CCE-LTER site is a major part of their research program and who has some overall project management responsibilities. Associates are engaged in the CCE site, but CCE represents a smaller part of their total research activity. In addition to co-PI's and Associates, the CCE website lists "Affiliated Personnel" including visiting scientists, graduate students, and others who typically participate in one aspect of the research (e.g., a single research cruise, or a short-term collaboration). Participation in CCE during Phase II included graduate students (46), postdocs (17), undergraduates (39), technicians (36), and volunteers (45), as well as extensive Affiliated Personnel from other institutions.

The site is managed by the Lead PI (M. Ohman), in regular consultation with the CCE Executive Committee (EXCO). The EXCO membership currently includes Mark Ohman (Chair), Kathy Barbeau, Charina Cain, Peter Franks, Ralf Goericke, Mike Landry, Art Miller, and a graduate student (Alexandra Freibott). These people represent each of the major elements of the CCE site: **Process Cruises** (Landry and Barbeau), **Augmented CalCOFI and other Time Series** (Goericke), **Modeling** (Franks and Miller), **Information Management** (Conners**), Education, Outreach, and Capacity Building** (EOCB, Cain), **Graduate Students** (Freibott) and different science specialties. The EXCO addresses science and budgetary priorities for the CCE site, periodically reviews progress on each of the major program elements, responds to new science initiatives, prioritizes supplement requests, and serves as a communication conduit for the rest of the site. The EXCO also discusses major writing projects, prioritizes ship time usage, and plans our Annual Meetings.

CCE employs a half-time Program Office Coordinator (Robin Westlake Storey). Ms. Storey coordinates meetings, communicates regularly with participants in the CCE site and with the LTER Network Communications Office, manages travel funds, assists with REU program management, maintains the site bibliography, and assists in assembling materials for annual reports and other documents.

CCE's Information Manager is James Conners, a member of the EXCO. Information Management is closely integrated into CCE site science, EOCB, and planning (see Data Management Plan).

The CCE Education, Outreach, and Capacity Building (EOCB) Coordinator is Charina Cain Layman, who also serves as the Public Programs Manager for the Birch Aquarium at Scripps (BAS). We are particularly pleased with the formal ties between CCE and BAS, as this provides a natural outlet for communication between the research and graduate training at SIO and the larger San Diego (and visitor) communities that are reached by the Birch Aquarium. Ms. Cain is a skilled educator and has fostered a number of creative interactions between the public and our LTER site. She also coordinates our RET (Research Experience for Teachers) program (see EOCB Activities in the Project Description above).

A graduate student (currently Alexandra Freibott) represents the interests of CCE graduate students and postdocs internally within the CCE site and to the LTER network. She coordinates the quarterly CCE graduate/student postdoc meeting, communicates student interests and concerns, and fosters interactions with grad students at other sites, most regularly at Santa Barbara Coastal and Moorea Coral Reef, with developing interactions with Palmer Station. The CCE graduate student representative also acts as one of three moderators of a new graduate student-initiated blog about LTER research experiences (*Short Stories About Long Term Research*). We added graduate student representation as a full member of the EXCO ~two years ago, and have found their involvement beneficial for the program and students alike.

Our REU program is coordinated by faculty member Kathy Barbeau, with assistance from CCE Program

Office Coordinator Robin Westlake Storey. The two develop advertisements, screen applicants (with particular attention to under-represented students), and help match students with CCE mentors (faculty/researchers, graduate students, or occasionally a postdoc).

Turnover of CCE Personnel and Management Succession Plan

At the beginning of Phase III, CCE will have a core of 27 co-PI's and Associates, three of whom (including one assistant professor) will be newly joining us, with an equivalent number rotating off. In addition to these people with long-term commitment to CCE, our Affiliated Personnel include numerous people who are engaged more transiently in field studies, other cooperative research, and joint publications, as documented in our list of publications on the CCE website. Two of the new Affiliated Personnel are Assistant-level women (Alison Pasulka and Fanny Chenillat). With five new participants at the beginning of Phase III, three of them female, we feel we have a healthy balance of new and continuing participants. The dynamism of the site is also ensured by the participation of numerous graduate students, who often challenge us to consider new directions. CCE has had, from the beginning, an open door policy toward collaborations, sample sharing, and data sharing, and actively encourages participation of new colleagues, including non-LTER personnel. We make this open door policy clear at national and international meetings, in one-on-one interactions, and elsewhere. We encourage participation by colleagues abroad, and have developed productive collaborations with colleagues in Japan, France, South Korea, China, Norway, Mexico, Portugal, and elsewhere. We are committed to enhancing diversity through participation by underrepresented minority groups and women at all levels ranging from REUs through faculty.

CCE's plan for project succession is for Mark Ohman to serve as lead PI for Phase III, with training and a gradual transition of responsibilities to co-PI Kathy Barbeau over the course of the grant. By the end of Phase III, Prof. Barbeau is expected to be leading the CCE Executive Committee and coordinating the development of new proposals. The leadership of each major program element will be openly discussed during our EXCO meetings, to ensure an infusion of new perspectives and younger scientists.

Communication within CCE

Internal communication within the CCE site membership is accomplished in several ways. (1) CCE holds an **annual meeting**, to which all participants in the site are invited. In most years off-site participants are encouraged to attend and travel support is provided; this past year, because of the added expense of travel to the LTER All Scientists Meeting in 2015, off-site participants participated by video conference. Our annual meeting usually lasts 1½ days and includes summaries of all program elements, updates, discussions of new horizons and any revised priorities. (2) The lead PI distributes "**CCE-LTER News**" by email, to ensure that all participants (and especially those located off-site) are up to date on current events and planning. (3) Other, less formal **e-mail** communications are used to relay news from the LTER network office, NSF, or other sources. (4) The **CCE Forum** is our informal seminar setting for presentations and discussions. A Forum is held as needed, to focus on a particular PI 's or graduate student's results, to share preliminary results (e.g., from process cruises), or other topical themes. (5) We regularly use **Video-conferencing,** typically in combination with previously scheduled meetings. (6) Graduate students have initiated a quarterly CCE student/postdoc meeting. (7) Participants in the **Process Cruises** (usually 32-34 CCE people at sea) have an excellent opportunity to interact informally at sea for approximately a month at a time.

Science and Budgetary Organization

As noted, the CCE site is organized around five core elements: **Process Cruises**, **Time Series Measurements**, **Modeling**, **Information Management**, and **Education, Outreach, and Capacity Building.** There are separate budgets for each of these elements and for project management. An individual co-PI is responsible for managing each budget. The lead PI has electronic access to all budgets and maintains overall oversight. When a new year's budgetary allocation arrives from NSF, these funds are distributed in the manner described in the budget pages in the original proposal. If an adjustment is needed to the original plan, or a new opportunity arises, the issue is discussed by the EXCO, and funds may be reallocated consistent with the proposal objectives.

The funds within CCE are distributed according to our agreed-upon needs for each program element, rather than proportionately to individual PI's. Most of the support goes to graduate students, technical support, materials and supplies, and sample analysis, and some to permanent equipment. Little support is paid as PI salaries; all co-PI's and Associates must seek additional funds elsewhere to complement the CCE-LTER funding. Travel funds are managed by the CCE project office. Discussions of needs for supplemental funds are conducted openly with the entire CCE group, and then the EXCO arrives at a prioritization of the supplement requests.

External Advisory Panel

CCE has an External Advisory Panel (EAP) comprised of three ecologists. Two are from non-marine LTER sites (Debra Peters, Jornada Basin and Paul Hanson, North Temperate Lakes) and one is a non-LTER biological oceanographer (Julie Keister, University of Washington). Previously Mark Brzezinski from the SBC LTER site (UC Santa Barbara) was on our EAP, but when his lab began directly collaborating with us on our process cruises, we replaced him in order to retain outside objectivity. The EAP attends our annual meetings, when possible, reports back advice to us in written form following the meetings, and provides feedback on proposals.

PM Table 1. CCE-LTER Participants in Phase III

Name	Role	Institution	Interests
Mark Ohman	Lead PI	SIO	Mesozooplankton Ecology
Lihini Aluwihare	Co-PI	SIO	Dissolved Organic Matter
Katherine Barbeau	Co-PI	SIO	Iron Geochemistry
James Conners	Co-PI	SIO	Information Management
Peter Franks	Co-PI	SIO	Biophysical Modeling
Ralf Goericke	Co-PI	SIO	Phytoplankton Ecology
Michael Landry	Co-PI	SIO	Food-Web Structure & Function
Art Miller	Co-PI	SIO	Physical Oceanography; Modeling
Michael Stukel	Co-PI	FSU	Carbon Export
Andrew Allen	Associate	SIO/JCVI	Microbial Genomics
Farooq Azam	Associate	SIO	Bacteria/Microbial Food Webs
Claudia Benitez-Nelson	Associate	UofSC	Marine Biogeochemistry
James Bishop	Associate	UCB	Marine Biogeochemistry
Steven Bograd	Associate	ERD	Physical Oceanography
Ron Burton	Associate	SIO	Molecular Probes for Ichthyoplankton
Charina Cain Layman	Associate	BAS	Education, Outreach, Capacity Bldg.
Emanuele Di Lorenzo	Associate	Georgia T.	Biophysical Modeling
Chris Edwards	Associate	UCSC	Ecosystem Modeling
Mati Kahru	Associate	SIO	Satellite Remote Sensing
Jennifer MacKinnon	Associate	SIO	Ocean Mixing
Todd Martz	Associate	SIO	Marine Chemistry
B. Greg Mitchell	Associate	SIO	Remote Sensing and Bio-optics
Brian Palenik	Associate	SIO	Microbial Diversity
Daniel Rudnick	Associate	SIO	Glider-based observations
Uwe Send	Associate	SIO	Moored observations
Ken Smith, Jr.	Associate	MBARI	Deep-sea Benthic Ecology
Bill Sydeman	Associate	FIAER	Seabird Ecology

SIO= Scripps Institution of Oceanography/UCSD; FSU- Florida State University;JCVI- J. Craig Venter Institute; UofSC- University of South Carolina; UCB – University of California, Berkeley; ERD= Environmental Research Division, NOAA Southwest Fisheries Science Center; BAS-Birch Aquarium at Scripps; LDEO= Lamont Doherty Earth Observatory; LEMAR= Laboratoire des Sciences de l'Environnement Marin, Plouzané, France; Georgia T.- Georgia Institute of Technology; UCSC= Univ. of California, Santa Cruz; MBARI=Monterey Bay Aquarium Research Institute; FIAER= Farallon Institute for Advanced Ecosystem Research