CANON / ECOHAB Spring 2013 Experiment Plan
20 February 2013

Spring experiment context

The spring 2013 experiment is the first of two planned collaborations between MBARI's CANON Initiative and the NOAA ECOHAB project entitled, *A Regional Comparison of Upwelling and Coastal Land Use Patterns on the Development of HAB Hotspots Along the California Coast*. Institutions participating in the ECOHAB project are UCSC (lead R. Kudela), MBARI, MLML, CeNCOOS, USC, SCCWRP, JPL and NOAA. This first experiment will take place in the San Pedro Bay region during March – April; the second experiment will take place in the Monterey Bay region during September – October (Fig. 1). While sharing some large-scale variability, and perhaps some local environmental characteristics associated with 'upwelling shadow' dynamics, the two regions have significant differences in atmospheric and oceanic forcing, as well as human-impact channels (agricultural runoff, sewage). The contrasting oceanographic settings and anthropogenic influences form the basis of a comparative study to understand the environmental factors controlling the initiation, evolution, and toxicity of HABs – focusing primarily on *Pseudo-nitzschia* spp. that can cause domoic acid (DA) poisoning, and secondarily on *Alexandrium catenella* that can cause paralytic shellfish poisoning. The fall experiment in Monterey Bay will encompass biogeochemical studies as well as HAB ecology.

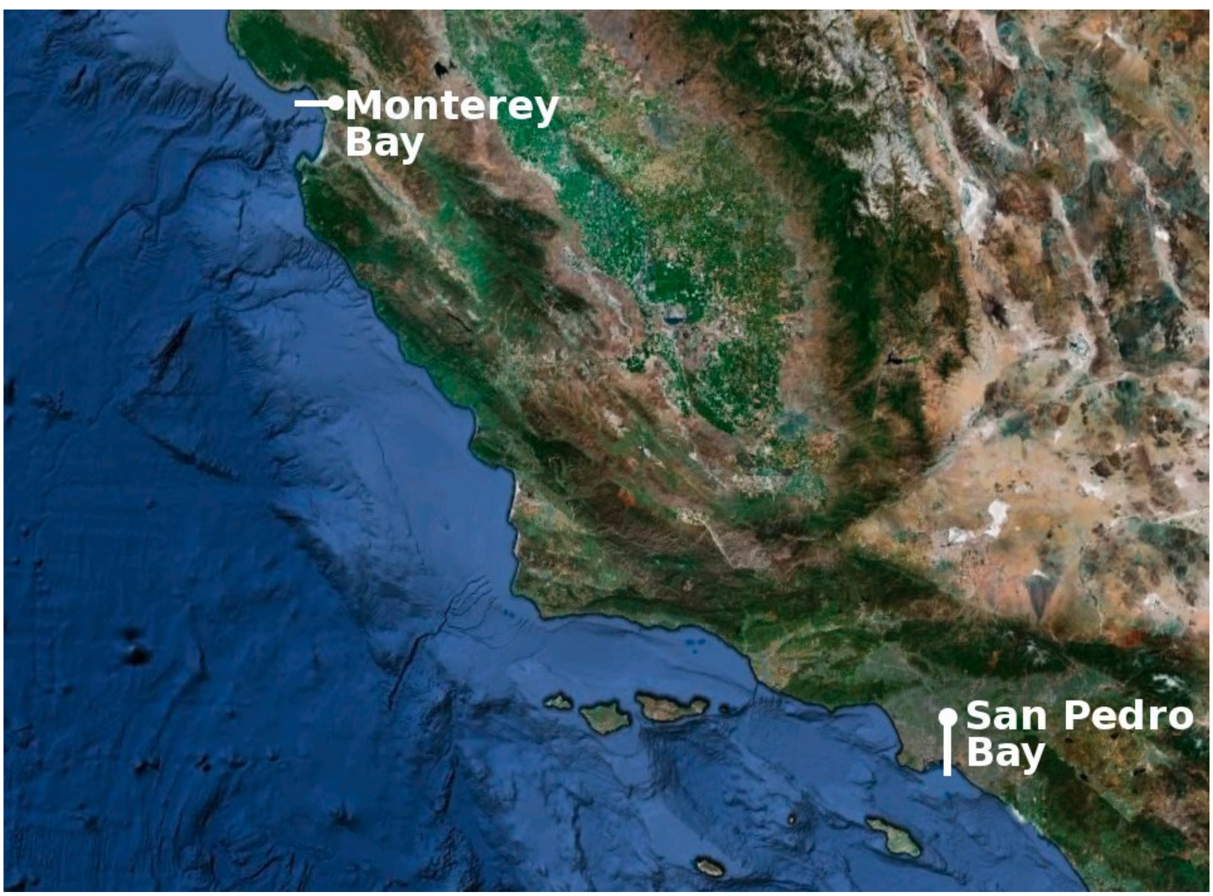

Figure 1. The two regions for 2013 CANON / ECOHAB collaborative studies.

In both regions, a key hypothesis is that subsurface layers, "hidden" from near-surface observing strategies, are critical to HAB population dynamics and bloom development. Also in both regions, episodic upwelling is key to HAB ecology. In Monterey Bay, persistent subsurface "thin layers", hosting dense populations of toxigenic *Pseudo-nitzschia*, have been documented (McManus et al., 2008). However, the prevalence and seasonality of such layers is unknown, and their ecology is not clearly understood. On the San Pedro shelf, previous studies including one that employed two Environmental Sample Processors (ESPs) in spring 2010, indicate that subsurface layers of *Pseudo-nitzschia* from the deep chlorophyll maximum (DCM) adjacent to the shelf seed bloom events on the shelf during upwelling events (Caron et al., 2011; Seegers et al., 2011, 2012). However, such seeding has never been directly observed, and the species composition and dynamics of the DCM on and off the shelf are not well characterized.

Asset deployment plan: overview

An overview of the asset deployment plan is presented here, followed by more detailed plans in subsequent sections. Most observing assets will be focused on the southern San Pedro Shelf — where *Pseudo-nitzschia* blooms have been observed during spring, previous HAB ecological experiments have been conducted, and risks from commercial shipping traffic are relatively low (Fig. 2).

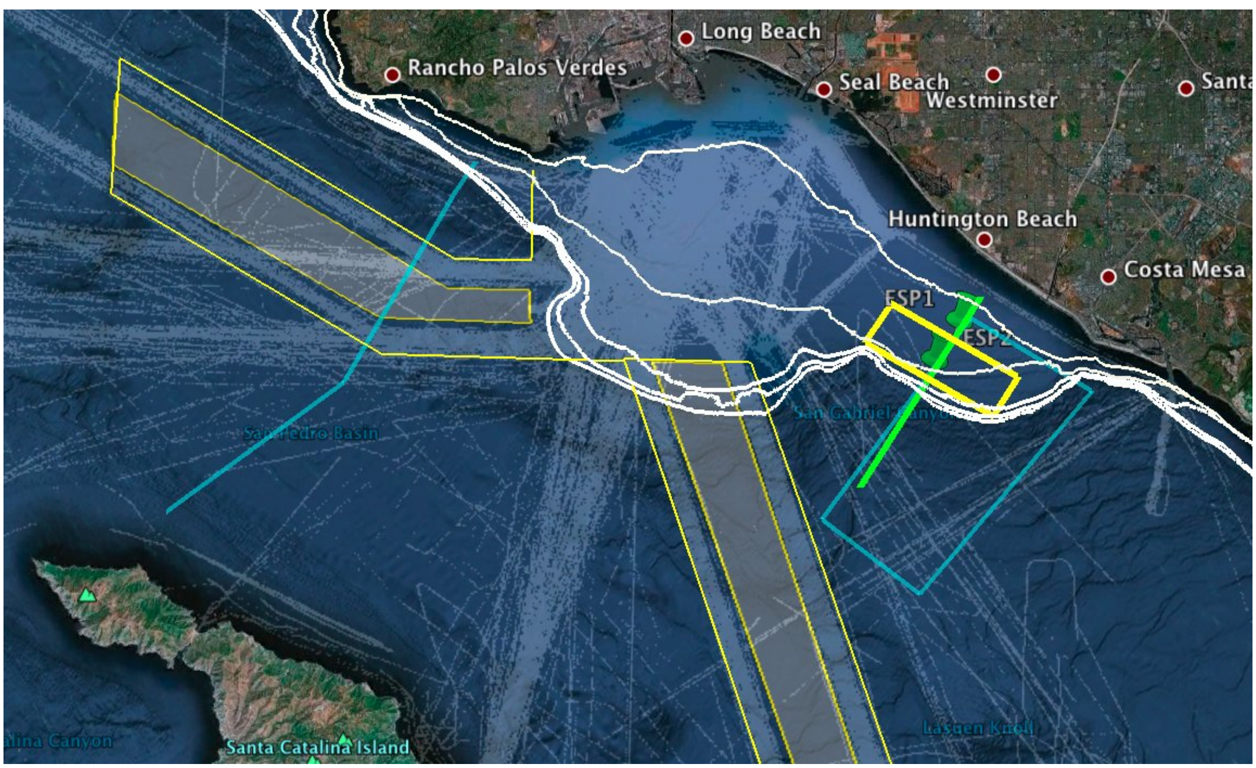

Figure 2. Asset deployment plan. White contours are isobaths (20:20:100); the shelf break is indicated approximately by the 100 m isobath. Colored lines are glider (cyan) and ship / propelled-AUV (green, yellow) survey paths (described below). Shipping lanes and density of commercial shipping traffic are indicated.

Pseudo-nitzschia populations that bloom in San Pedro Bay are hypothesized to originate from the deep-chlorophyll maximum (DCM) NW of the bay, and to be advected onto the shelf during upwelling. Considering along-shelf transport to the southeast ('down coast') during upwelling, a cross-channel section between Palos Verdes and Santa Catalina Island will resolve conditions immediately upstream of where phytoplankton populations may first advect onto the San Pedro shelf, i.e. at the northern end of San Pedro Bay (Fig. 2). USC will maintain a glider along this section between late February and late April.

Geographic specifications of moorings and survey tracks are in Appendix 1, and the deployment schedule is shown in Fig. 3. Providing periodic molecular detection of HAB species and DA, the ESP moorings establish an organizational footprint for other moored and mobile observing assets. Their locations (Fig. 2, green pins) are those used in the 2010 experiment. While the geographic locations used in 2010 were effective and thus considered a good plan for 2013, modifications to ESP sampling depth were motivated by analysis of the 2010 glider data. In 2010, both ESPs resided at ~17 m. In 2013, we will deploy the outer shelf ESP deeper (25 m, intending to better sample DCM populations) and the mid-shelf ESP shallower (10 m, intending to better sample mixed layer populations). See Appendix 2 for a summary of the glider data analysis used to inform these deployment parameters. ESP adaptive sampling will be informed via integration of information from AUV surveys and ESP contextual sensors (described in a subsequent section).

The cross-shelf/channel section parallel to the ESP array (Fig. 2, green line) will be occupied by ships and AUVs. One of two long-range AUVs (LRAUVs) will provide nearly continuous coverage along this section for two weeks. The Dorado AUV will survey this section, autonomously targeting water sampling within phytoplankton patches (in the DCM or mixed layer) during a series of day operations (Fig. 3). Ship CTD sampling concurrent with AUV operations will support more extensive measurements of environmental and biological variables, as well as experiments with phytoplankton, to be integrated with the high-resolution information from the AUVs. The yellow box represents the planned track for the second LRAUV, to provide along-coast coverage with the same persistence and high temporal resolution of the first LRAUV. Operations of the R/V Yellowfin will be coordinated with those of the R/V Carson. The cyan lines show the planned tracks for two USC gliders, one monitoring transport between the hypothesized source region for *Pseudo-nitzschia* populations and San Pedro Bay (section off Palos Verdes), and the other monitoring the southern shelf and adjacent channel (repeat every ~ 2 days).

The intensive phase of the experiment is defined as the period during which the R/V Rachel Carson will serve as a hub for collaborative day-cruise operations coordinated with R/V Yellowfin operations, March 15-22, (Fig. 3). Prior to the intensive, USC gliders, ESPs, LRAUVs, a Wire Walker, the R/V Yellowfin, and the ROMS model will be applied for ecosystem characterization. During the intensive, informed by near-real-time data, we will apply alternate strategies using the R/V Carson and Dorado AUV. These strategies are essentially Eulerian and Lagrangian approaches to studying HAB ecology; they are sketched below. If available, a Waveglider may also contribute. The Regional Ocean Modeling System (ROMS) will be "deployed" for both nowcast and forecast analyses.

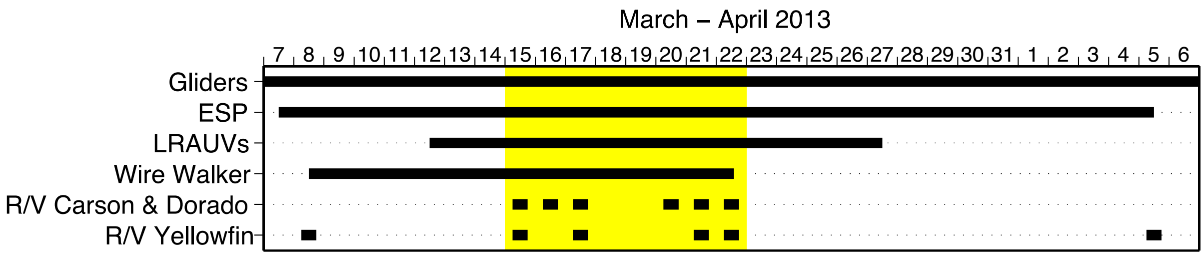

Figure 3. Asset deployment schedule. The intensive phase is highlighted. USC gliders will be deployed beyond the period shown, ~ February 27 through April 27.

Focal hypotheses

The observing and modeling system will be applied to characterize ecosystem structure and processes, and to address focal hypotheses:

- Toxigenic *Pseudo-nitzschia* populations reside / are concentrated in the DCM.
- Favored by upwelling circulation patterns, *Pseudo-nitzschia* populations enter the San Pedro shelf ecosystem to initiate toxic blooms.
- Bloom growth in the bay is supported by enhanced nutrient and light conditions accompanying the upwelling / advection of DCM populations.

Additional questions and hypotheses will be addressed as well, e.g. in comparison between phytoplankton ecology during the fall 2012 OCSD diversion experiment and spring 2013.

Transport pathways

Transport pathways for the DCM between the hypothesized source region and the southern San Pedro shelf (focal study region) are not well defined. Satellite SST images, indicative of transport patterns in the upper water column, show that during spring the transport of recently upwelled waters to the southern shelf may be focused along the middle, inner or outer shelf (Fig. 4). CODAR climatology and ROMS trajectory analysis (in progress) will inform this further. Understanding the transport pathways during the experiment will be key to interpreting the localized observations (Fig. 2).

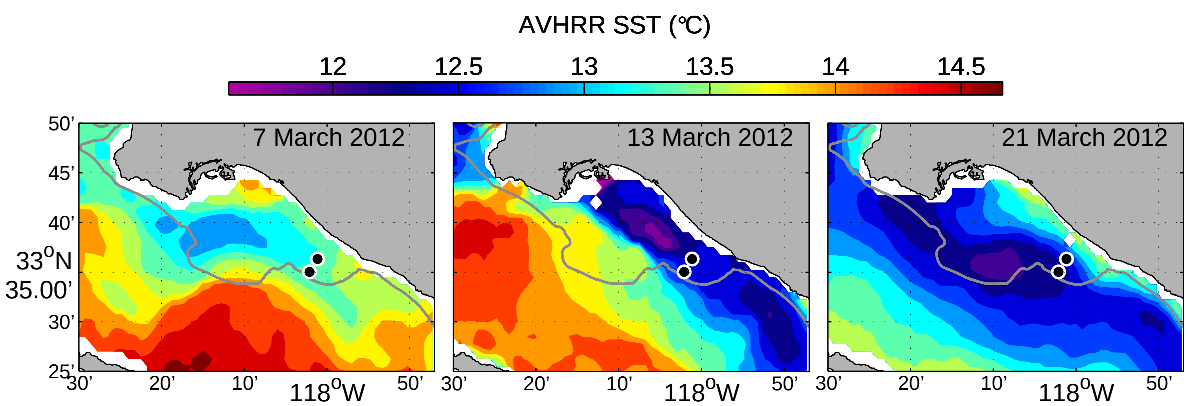

Figure 4. SST images from March 2012, representing different apparent transport pathways for recently upwelled waters to the southern San Pedro shelf. Circles show the ESP mooring locations for the 2010 and 2013 experiments.

R/V Rachel Carson & AUV Dorado surveys

Capabilities of the Dorado AUV that are particularly valuable to experiment goals include its multidisciplinary sensing / imaging, high speed surveying, a sample acquisition system, and well developed control for adaptive navigation and water-sample acquisition. The value of Dorado observations will be greatest by conducting ship and AUV observations concurrently in the same area. During the intensive phase (Fig. 3), R/V Carson and Dorado operations will be conducted in two modes: (1) Eulerian-framework observations along the central cross-shelf section (Fig. 2), and (2) Lagrangian-framework observations, based on tracking a drifter drogued in the DCM. During mode 1 surveys, ship and Dorado sampling around and offshore of the ESP array and sampling within/outside the DCM will effectively define relationships between shelf populations of *Pseudo-nitzschia* and the DCM seaward of the shelfbreak. The first day of each 3-day survey block (Fig. 3) will be dedicated to this detailed ship/AUV mapping across the central cross-shelf section. The operational mode for the second and third days of each 3-day block will be determined based on near-real-time results from the greater observing and modeling program. For example, if ship / AUV observations define a strong DCM off the shelfbreak near the focal study region, and sampling determines that the DCM contains significant populations of *Pseudo-nitzschia*, then we will tag the DCM with a drifter and employ ship and AUV assets to observe transport of DCM populations, resolve influential processes along the transport trajectory, etc. This decision will be made each morning.

For mode 1 (section) surveys (Fig. 2), simple AUV navigational control (MVC) and an established peak-capture algorithm (Zhang et al., 2010; Ryan et al., in press) will serve effectively. The goal is to acquire exceptionally synoptic, high-resolution, multidisciplinary description of the environment and plankton community (including plankton imaging), as well as precisely targeted sampling within and outside of the DCM. Considering the length of the section, a complete AUV survey with acquisition of up to 10 Gulper samples will require ~ 2 – 2.5 hours. Therefore, we will conduct two Dorado sections (outbound, inbound) in a single day operation. Ship CTD sampling will follow behind Dorado on both outbound and inbound surveys, and thus acquire the full CTD section in a sequence that meets in the middle. Ship CTD profiles will be as dense as possible, considering the survey time window, station time, transit speed, and Dorado turnaround. Nominal CTD stations have been defined (Appendix 1), and we will subset from these as required. The top priority will be to sample both the shelf, particularly next to the ESPs, and the DCM in the channel, if present.

For mode 2 (Lagrangian) surveys, navigational control requirements are greater, and here we will use established capabilities of T-REX to autonomously track and map repeated volumes around a drifter. Selection of a Lagrangian mission will be based on the presence of a DCM at / near the outer shelf ESP. The intensive AUV observations (described above) will provide description of the presence, intensity, and scale of the DCM, and microscopic examination of recent samples will provide description of phytoplankton community composition. The ideal case is the presence of a *Pseudo-nitzschia* enriched DCM, however we will consider Lagrangian experiments for the purpose of process studies even in the absence of a significant *Pseudo-nitzschia* population. The ESP mission design will permit synchronization of ESP sampling and initiation of a Lagrangian experiment to track phytoplankton populations at the depth of the ESP. Ship CTD profiles will be acquired next to the drifter at a periodic interval throughout the day. Whether the drifter is recovered at the end of ship day-operations or left out to be returned to the next day will depend on the anticipated overnight trajectory of the drifter. As successfully applied in multiple T-REX patch-tracking missions, we will use the peak-capture algorithm on Dorado to acquire samples from within and outside the DCM. Additionally, Dorado's "surgical sampling" capabilities may be further augmented by JD, who is developing an environmental niche model for prediction of *Pseudo-nitzschia* hotspots in San Pedro Bay. If the model is demonstrated to be effective with available (mostly surface) data sets in a way that is applicable to a subset of Dorado measurements available in real-time, its operation onboard Dorado may be tested during the experiment.

Long-Range AUV (LRAUV) operations
LRAUVs Tethys and Daphne will be active preceding, during and following the intensive phase (Fig. 3). They will occupy two sections: (1) the central cross-shelf / channel section (same as that occupied by Carson/Dorado/Yellowfin), and (2) a box survey that provides along-coast coverage. Both survey types will pass by both ESPs. We anticipate six cross-shelf sections and three box surveys per day. Survey parameters may be slightly modified from definitions in Appendix 1, to ensure a consistent and effective strategy for sampling and data transfer.

R/V Yellowfin operations
The R/V Yellowfin will conduct a survey of the Carson cross-shelf section prior to the intensive. During the intensive, on days when the Carson occupies the cross-shelf section, the Yellowfin will conduct complementary sampling. On days when the Carson conducts Lagrangian DCM tracking and observation, the Yellowfin will occupy the central cross-shelf section.

Water sampling group plan
Water samples will come from CTD rosettes on the R/V Carson and R/V Yellowfin, and from the Gulper water sampling system on the Dorado AUV. The following details emerged from discussions.

R/V Carson

- With 12 10-L bottles, a single CTD cast will provide sufficient water for all water users.
- The Kudela Lab will use water only from ship CTD samples, not AUV Gulpers.
- Jason Smith will bring microscopes for at sea and dockside microscopy.

AUV Dorado

- The Gulper water budget is (each gulp 1.8 L): 500 ml to Caron lab and Holly, 400 ml to Meredith and Tanya.

R/V Yellowfin

- Yellowfin sampling will augment Carson sampling and be adaptive to the type of survey Carson / Dorado are running.

- Caron lab will run grow-out experiments on shore from Yellowfin samples only.

Growout experiments (Kudela, Caron) will vary nutrient amendments and light intensity.

ESP adaptive sampling
Data from multiple mobile platforms and model predictions may inform the ESP sampling schedule. Adaptive sampling planning for the 2013 San Pedro Bay experiment has considered use cases involving previous adaptive sampling applications, existing capabilities on ESP as well as some recent developments, hypotheses and associated observing goals, and asset deployment schedules. Simulation of missions is ongoing using the 2010 ESP contextual data set. Below are sketches of the primary use cases.

a. Response to a temporal trend in ESP contextual sensors
The rise of *Pseudo-nitzschia* signal during the spring 2010 San Pedro Bay experiment followed a significant upwelling pulse (Seegers et al., 2011, 2012). Identification of this environmental signal, as detected by ESP contextual sensors themselves, thus forms the first use case for adaptive sampling. Based on the 2010 data, we define a decrease of 2°C relative to 'background' temperatures during the preceding 3 days (methods developed and tested by Y. Zhang) as the indication of the arrival of an upwelling pulse. This signal will prompt acceleration of the ESP sampling schedule, to resolve physical-biological coupling through the environmental transition. The nominal acceleration will be 12-hourly sampling for a period of two days followed by daily sampling for a period of three days. This sampling scheme is designed to observe effectively from low abundances in recently upwelled waters to peak abundances in aged upwelled waters.

b. Response to feature detection and description
Environmental and bio-optical conditions around the ESPs will be intensively monitored with synoptic, high-resolution mapping from LRAUVs, Dorado, and a USC glider (Fig.2). A key feature detection from these AUV data will be the presence of a DCM around the ESP mooring(s). Based on the detection and description of the DCM (scale, vertical distribution relative to ESP depth, intensity within the ESP contextual time-series), this feature detection and description may motivate use of one or more ESP samples. In this use case, we may also synchronize an ESP sampling event with the start of a Lagrangian experiment (as described above for Dorado AUV operations).

Other, more complicated, adaptive sampling scenarios were considered, including the use of proxy relationships to relate remote feature detection by AUVs to local sampling thresholds at the ESPs. Proxy relationships (e.g. T-S-Chl) were examined for the 2010 glider data set and found to be highly variable, thus requiring highly local observations (in space and time) to be effective. Further, uncertainty in defining proxy variable ranges that uniquely define the remote feature and its relationship to conditions at ESP, and uncertainty in predicting the trajectory of the remote feature introduce much speculative risk to effective adaptive strategies.

Appendix 1: geographic specifications for asset deployments

ESP moorings will be deployed at the following locations:

- Outer shelf (~ 55 m water depth): 33.5839, -118.0349 (33° 35' 02.1", 118° 2' 05.7")
- Mid shelf (~ 30 m water depth): 33.6055, -118.0191 (33° 36' 19.8" 118° 01' 08.7")

The endpoints of the central cross-shelf/channel section are:

- inshore: 33.6333, -118.0000,
- offshore: 33.5167, -118.0833

Nominal CTD stations along the central cross-shelf/channel section are:

1. 33.6333 -118.0000
2. 33.6194 -118.0095
3. 33.6055 -118.0191 (next to mid-shelf ESP)
4. 33.5947 -118.0270
5. 33.5839 -118.0349 (next to outer-shelf ESP)
6. 33.5667 -118.0476
7. 33.5500 -118.0595
8. 33.5333 -118.0714
9. 33.5167 -118.0833

The corners of the LRAUV survey box are (starting eastern-most and running CCW):

1. 33.5864 -117.9769
2. 33.6250 -118.0589
3. 33.6036 -118.0756
4. 33.5653 -117.9928

Appendix 2: ESP depth specification
This summary of USC glider data from the spring 2010 San Pedro Bay experiment is used to inform decisions about ESP deployment depths for the spring 2013 experiment. During this experiment, two ESPs was deployed: (1) in outer shelf waters, ~ 55 m water column depth, and (2) in mid-shelf waters, in ~ 30 m water column depth. For both moorings, the ESP intake was ~ 17 m. Whether this depth was optimal for sampling potential populations of toxigenic *Pseudo-nitzschia* can be addressed by analysis of glider data (Fig. 5). Although the data from a single experiment are not sufficient to characterize regional statistics, glider data from the 2010 experiment is a good start. The spatial sampling irregularity of the glider data complicates accurate representation of synoptic sections, therefore this initial analysis focuses only on examination of vertical structure from aggregated profiles.

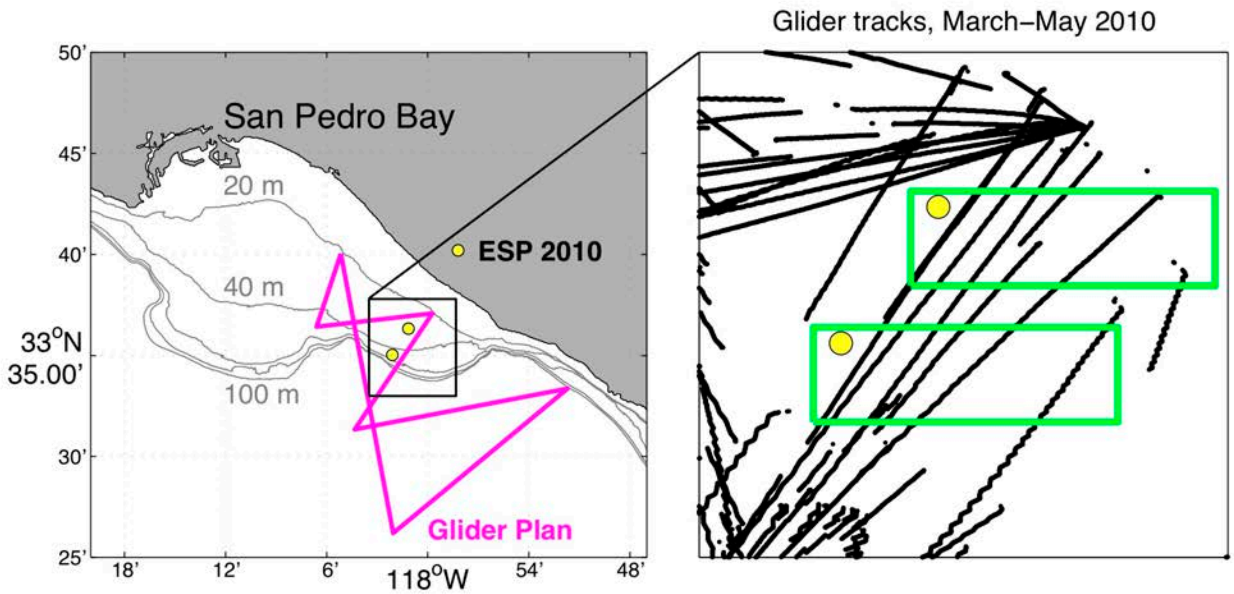

Figure 5. Planned and actual glider tracks from the spring 2010 experiment relative to the ESP deployment locations. The green boxes define the domains from which glider profile data are examined for water column structure in the mid- and outer-shelf regions.

Outer shelf ESP
At the outer shelf location, ESP Bruce showed a sharp rise in *Pseudo-nitzschia* signal during April 21-25. This rise began during a sharp decline in temperature (~ 4°C), and it continued steadily as temperatures oscillated at intermediate levels between the warmest conditions that preceded the upwelling pulse and the coldest conditions of the initial upwelling pulse (Caron et al., 2011; Seegers et al., 2011, 2012). The local glider data during this period did not exhibit a DCM, and optical backscattering data indicated a moderate particle maximum closer to 8 m depth (Fig. 6, highlighted column). Therefore, the glider data do not indicate that the outer shelf ESP was too shallow to capture the relevant biological signal. Further, the subsequent glider pass by this ESP mooring showed maximum signal of both chlorophyll fluorescence and backscattering by phytoplankton above the ESP deployment depth. The only definitive DCM (i.e. coincident with a peak in optical backscattering (bb) and thus indicating a true peak in biogenic particle

concentrations) was observed during the May 4 pass, centered near 25 m depth (Fig. 6). The only other indication of a DCM in this area was observed on March 31, however it did not coincide with a peak in bb and is thus not indicative of a true maximum in phytoplankton abundance (Fig. 6). High bb below the chlorophyll fluorescence maximum was evident throughout the time-series, suggesting the presence of suspended sediments variably coupled with phytoplankton populations. This has been found to be of potential significance to *Pseudo-nitzschia* toxicity in Monterey Bay (Ryan et al., 2011, in press).

Mid-shelf ESP
ESP Mack detected a rise in *Pseudo-nitzschia* signal during April 27-29. This rise occurred during the same period of oscillatory temperature variation following the upwelling pulse (Caron et al., 2011; Seegers et al., 2011, 2012). The local glider data during this period also did not exhibit a DCM. Instead, chlorophyll fluorescence and bb indicated relatively homogeneous phytoplankton signal throughout the upper 20 m (Fig. 7, highlighted column). The glider time-series indicates that a clear DCM was never observed at this location, and that the 17-m ESP depth was often below the surface mixed layer, and thus not ideally placed for examining mixed layer phytoplankton populations.

In summary, while both ESPs detected rising *Pseudo-nitzschia* signal in association with response to an upwelling pulse, neither detection coincided with the presence of a DCM. Thus, the data do not indicate that deeper placement of ESP would have been more optimal for sampling phytoplankton maxima in the water column at either site when *Pseudo-nitzschia* populations were detected. Only one observation of a DCM, representative of a true peak in particle concentrations, was made: at the outer shelf site and centered near 25 m depth. The USC glider time-series suggests that this was during the mature phase of biological response to upwelling (when temperatures had warmed and chlorophyll concentrations were highest). However, the ESP sampling was completed before this phase of the upwelling response.

Depth specification:
Considering the goal of ESP sampling within the DCM, the 2010 glider data relative to outer shelf ESP results motivate placing ESP deeper at this location. Although a very limited sample of water column structure, it is the data we have. If we assume it to be representative of the mature phase of a spring bloom event, then the depth of 25 m is specified. At the mid-shelf location, the consistent pattern of ESP being located below the surface mixed layer motivates shallower placement to effectively sample mixed layer populations. We specify 10 m.

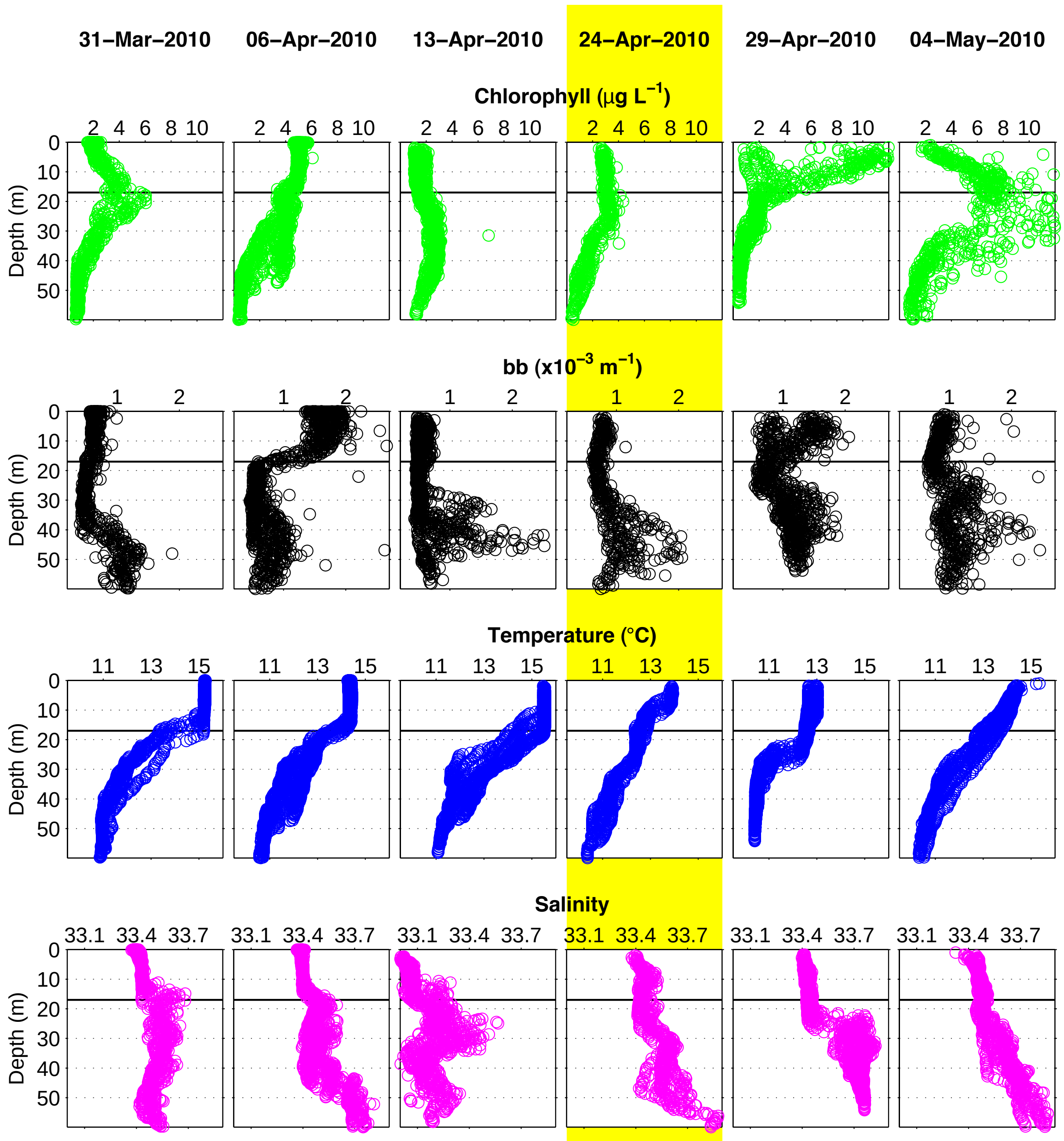

Figure 6. Glider profile data from the outer shelf domain (Figure 1). The highlighted data coincided with the local rise of *Pseudo-nitzschia* signal.

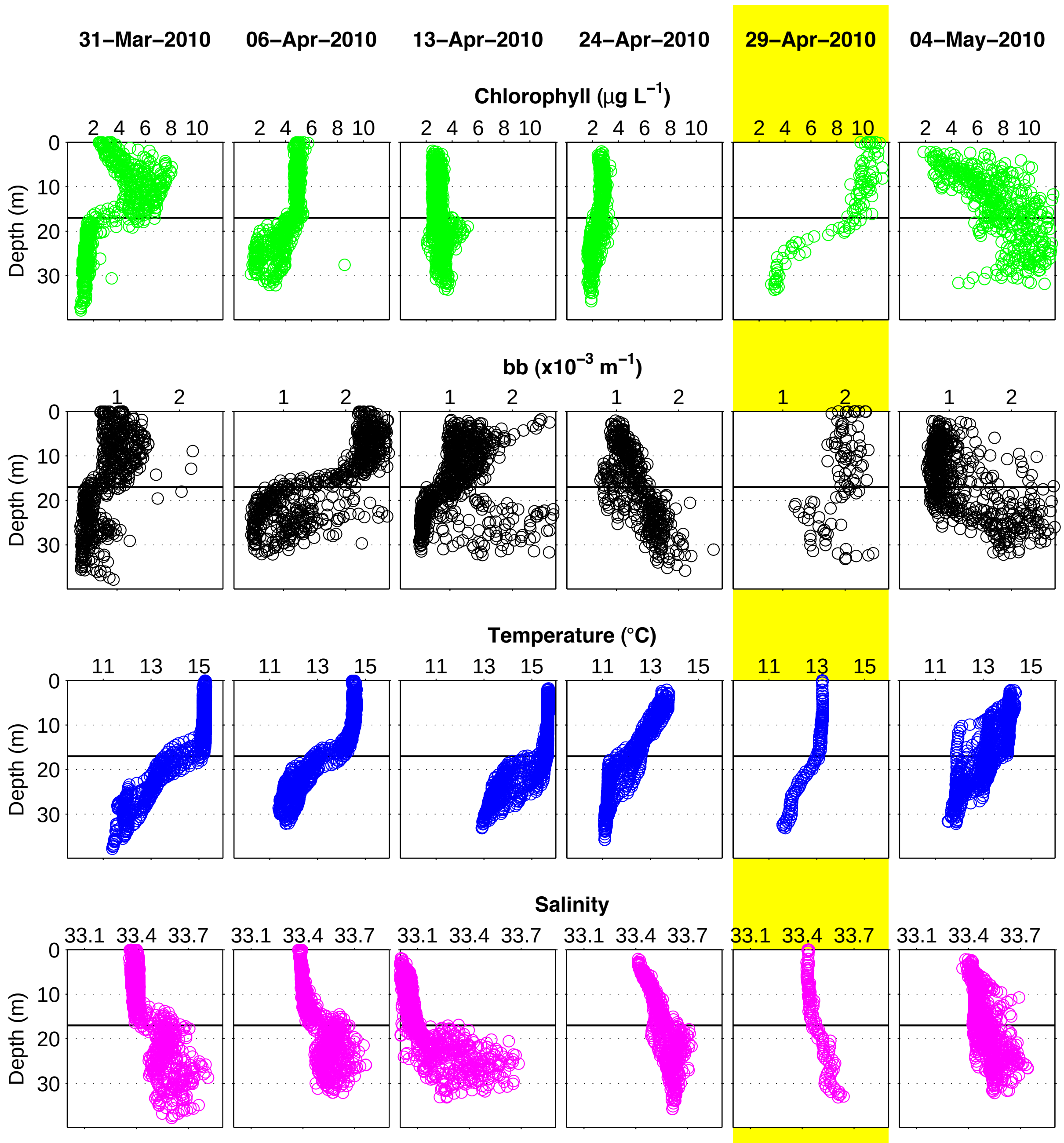

Figure 7. Glider profile data from the mid-shelf domain (Figure 1). The highlighted data coincided with the local rise of *Pseudo-nitzschia* signal.