Project Number: 900403

Project Start: Jan 1, 2005 **Project Duration (in years):** 2

Please indicate what type of project is being proposed (mark all that apply).

Feasibility/Scoping	Development	Research	Infrastructure	Education
	X			

Project Manager/PI: Alana Sherman

Project Title: AUV Gulper

1) ABSTRACT (new and continuing projects)

Although the AUV is currently equipped with a wide array of sensors, important science remains inaccessible to underway instrument readings alone. Many applications require a sample of water for analysis, for example plankton and larval ecology, Harmful Algal Bloom (HAB) detection, and sediment transport / carbon flux. AUV onboard intelligence provides a unique opportunity to adaptively acquire water samples within a multidisciplinary oceanographic context. The value of an on-board water sampling system can be measured by the amount of interest within the institute. Chris Scholin, John Ryan, Steve Haddock, Bob Vrijenhoek, Peter Girguis, BOG, and Zbigniew Kolber have all shown interest in an AUV water sampler and have participated in the process of determining functional requirements of such an instrument.

The ability to take a water sample aboard the AUV has been explored and sought at MBARI for years. During 2004, we conducted a feasibility study to define science uses and engineering functional requirements of an AUV water sampling system. The project team and user group defined a set of functional requirements that met most users' needs: 1-2 L volumes, 12 samples, and whole water samples with no processing or filtering. There was consensus among users that the sampler must be capable of acquiring a single sample rapidly (<10 sec/sample), and taking multiple samples in quick succession (3 samples over 10 vertical meters) without modifying the current AUV flight pattern. Keeping these requirements in mind, the project team and user group reviewed the specifications of various commercial water samplers, all of which would need to be modified for AUV use. The group determined that off-the-shelf samplers would not meet the requirements for rapid sampling. Relaxing the rapid sampling specification by a factor of ten would still not be enough to make a commercial device a viable option. Thus, we would need to design and build a system in-house. We will work to create a simple design that leaves the door open for future development (water sample filtration, particle preservation, large number of small water samples).

We propose a 2-year program to develop an AUV water sampler. The first year of this program will be spent designing, building and testing prototype components. The goal at the end of the first year would be to have a preliminary design based on the results of our testing. The second year would begin with preparation of detailed designs, followed by a critical design review, fabrication of the device, integration onto the AUV, and engineering field tests. The project team assembled for this purpose includes researchers (Scholin, Ryan, Friederich), and engineers (Shane, Sherman, Hamilton, McEwen). The project team plans to work closely with AUV operations (Thomas) through all stages development and integration.

2) PROPOSAL

a) The problem addressed (new projects only)

Statement of the problem

The spectrum of measurements being made from the MBARI AUV is outstanding, and the science enabled by these measurements is thus broad and multidisciplinary. However, important science remains inaccessible by underway instrument readings alone. Many important applications require a sample of water for analysis; for example plankton and larval ecology, Harmful Algal Bloom (HAB) detection, and sediment transport / carbon flux. AUV onboard intelligence provides a unique opportunity to strategically acquire water samples within the interpretive context and real-time decision matrix of AUV sensor measurements and computational resources.

Why it is important

The importance and potential of this technology development project is reflected in the strong interest expressed by multiple research groups within MBARI during the science use discussions that took place as part of the AUV Gulper scoping project in 2004. Use cases are summarized in Appendix A.

Present state of art/understanding

The project team and user group have evaluated the commercial water sampler options in light of our functional requirements. Please refer to the Results section for a detailed discussion of this topic.

How it relates/contributes to MBARI's mission and strategic plan

There has been long-term interest in developing an on-board water sampler for the AUVs at MBARI. This project proposes to create one instrument, which will enhance the science programs of five of MBARI's science groups (Ryan, Scholin, Haddock, BOG, Vrijenhoek). The AUV gulper would capitalize on platforms already available, while developing a resource unique to MBARI. A water sampling system can also be a valuable tool used in conjunction with ocean observing programs, or as a feature on a docked vehicle.

b) Approach to the problem (new and continuing projects)

Status of project

We proposed in 2004 to complete the following tasks as part of the feasibility study:
1) clearly and thoroughly define science uses
2) establish functional requirements from science use definition
3) evaluate existing technologies to determine whether this capability on the Dorado AUV will best be realized by modification of a commercial system or design and build of a system in-house

We have completed each one of these goals. Depending on time and resources, we hope to continue to evaluate concepts and potential system components in the next few months. Next year we would like to transition from a scoping project to a development project.

Results to date

We have held multiple meetings with our user group in the past year. Through these discussions, we developed a set of functional requirements that meet the needs of most users:

1. Raw water samples (no filtering): Although the users were primarily interested in particles, as a group we decided that filtering particles from the water would require a more complex system than we are prepared to attempt at this point.

2. Sample volumes between 1-2 L: Following from the first requirement, large volumes of water are needed to collect enough particles for meaningful sample analysis. The volume required to get an adequate "signal" has been experimentally determined by several users (Haddock, Vrijenhoek, Scholin).

3. Number of samples between ~12: This value will depend on the space and weight constraints of the final design.

4. Sample inhalation rate < 5 sec: Several of the users are interested in sampling plankton layers while running a standard transect. This poses a design challenge because it necessitates capturing a large volume of water in a short time. There are two approaches to satisfying this requirement: (a) to design a system capable of very rapid inhalation (i.e. big pump), or (b) to modify the vehicle's trajectory in an attempt to prolong the period during which the vehicle is within the layer of interest. We plan to attempt the former, since it allows scientists to maintain their trajectories and correlate sampling with previous studies along the same trajectory. Furthermore, relaxing the rate of inhalation does not necessarily result in an easier solution. Changing the vehicles trajectory would be an attractive approach if it enabled us to use a commercial system, however this is not the case (unless the vehicle came to a complete stop). While we remain open to the idea of using vehicle control to ease or satisfy some of our requirements if possible, we will attempt to design a system that can meet this requirement without drastically interrupting the current vehicle operations.

5. Ability to take multiple samples in rapid succession: This requirement also stems from plankton layer applications. In order to get three discrete samples over approximately 10 m while moving at 3 knots, we need to be able to index quickly between sample containers.

6. Vertical resolution of 3 m, horizontal resolution of 300 m. The vertical resolution requirement is motivated by plankton layer applications.

7. Depth rating of 200 m.

8. Retaining all current measurements from contextual sensors: Adding the sampler must not result in the removal of any of the current sensors in the system. Furthermore, we need to put some thought into making it easy to collocate data points.

In addition to these functional requirements, the following constraints must be considered in the design:
1. Space available in the mid-body of the CTD vehicle
2. Power available from the vehicle (80 A at 30V)
3. Weight of the payload
4. Vehicle control and stability
5. Placement of the water intake and other hydrodynamic issues

The project team together with the users group has evaluated commercial samplers from Environtech, McLane, Challenger Oceanic, and Chelsea Technology Group. A table compiling the specifications of these samplers is included in the appendix. The concerns with these samplers include: rate of sampling (up to 8 minutes per 1L sample), size of samples, and size of instrument. While we might be able to get around the size issues with some of these devices, the sampling mechanisms used (syringes, for example) fundamentally limit the rate of sampling. Even if we relaxed our required inhalation rate by a factor of 10, the commercial devices still would not meet our needs. Furthermore, each one of these systems would still require integration into the AUV, which will be one of the most difficult aspects of the project. Thus, the project teams conclusion is to design and build a system in house.

Plans for 2005

Engineering/technology development

In evaluating user needs and available samplers and components, it has become very clear that building a successful on-board water sampler is a very challenging endeavor. In order to increase the likelihood of this program's success, we propose to spend the first year evaluating and prototyping key components. At this point, we believe the high-risk elements of the system include (but are not limited to): sealing sample containers, pumping large volumes of water, designing a robust indexing mechanism, AUV integration, and preserving sample integrity. To thoroughly address these issues we will use both analysis (hydrodynamics and controls) and prototyping. Once parts are prototyped, we will evaluate them in the test tank, and on the AUV. Just catching one sample of water on the AUV, or confirming that an actuation mechanism functions during typical operations, would be a valuable learning experience. Our goal is to mitigate the risks inherent to this project and end the year with a well thought out preliminary design.

We propose the following plan for 2005:
1. Continue evaluation of water sampling components and systems
2. Conduct hydrodynamic analyses to determine optimal water intake and sampling strategy
3. Hold a concept design review
4. Build prototypes of key components for testing and evaluation. These components would probably consist of containers, valves, and an indexing mechanism.
5. Test prototype components in test tank
6. Test components on AUV
7. Analyze results of testing, modify components and system design accordingly
8. Preliminary design review

Field programs

No field programs are planned specifically as part of this project. However, if components are ready for testing on the AUV by September 2005, there will be multiple opportunities for basic *in situ* testing in association with Dorado operations funded externally through the LOCO project (708446) or internally through OCCO (900533). This may be as simple as acquiring a single sample to fully test sample triggering, containment, and return.

Data reduction and analysis

Dorado science data reduction is well developed and is being integrated with the data and metadata management of SSDS.

Significant changes from previous project proposal (continuing projects only)

This proposal is for a development program based upon feasibility and scoping project of 2004.

c) Specific deliverables (new and continuing projects)

Year 1 deliverables:

- Concept design review
- Hydrodynamic analysis
- Component prototypes
- Results of test tank and AUV component testing
- Preliminary design

d) Project team (new and continuing projects)

- Alana Sherman: project manager, electrical/system engineering, testing of components.
- Farley Shane: mechanical engineer, design, prototyping, and evaluation of component.
- John Ryan & Chris Scholin: lead scientists
- Gernot Friederich: evaluation and testing of components
- Andy Hamilton: will use expertise in hydrodynamics to optimize sample intake, and characterize hydrodynamic effects that may jeopardize sample integrity.
- Rob McEwen: analysis of the impact of the sampler on vehicle control and dynamics.

Project lab space (new and continuing projects)

Existing AUV and ME lab space will be sufficient.

3) BUDGET JUSTIFICATION (new and continuing projects)

Materials and Supplies:

We will need to buy or purchase materials for a the following components to develop and test a prototype water sampling system:

Sample containers - $2000

Closure mechanisms (valves) - $3000

Indexing mechanism - $2000

Indexing motor - $2000

Motion controller and driver - $3000

Mounting rack - $1200

High volume pump - $3000

Power supplies/electronics- $1000

In addition to these components, we also ask for a general supplies budget of $4000, and $1000 for tools. We would like to request a surplus laptop computer from IS, which we could use for testing and interfacing during bench top and tank testing. We have included $1000 for miscellaneous computer hardware and $1500 to purchase any software needed to interface and control the device.

Finally, we request a travel budget of $3000, for domestic travel to vendor sites and/or a conference for two people, with an addition $500 for conference fees.

4) MILESTONES (new and continuing projects)

	Milestone 1	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[1] for each resource category for all milestones listed here
Milestone Date	March 1	May 1	July 15	September 15	Nov 1	
Milestone Description	Concept review of system	Prototype components built	Tank testing of components completed	AUV testing of components completed	PDR	
EE	10	10	10	10	10	50
SE					15	15
ME	20 (10 Hamilton)	15	10	10	10 (5 Hamilton)	65
Machine Shop		15				15

[1] This number should be the same number you entered on the resource requests for this particular resource.

APPENDIX A: SCIENCE USE CASES

Haddock Lab
The operational capabilities of AUVs are rapidly improving, so that unattended surveys of physical and optical oceanographic properties may be conducted across large ranges. While our ability to gather high-resolution data increases, however, we are still dependent on ship-based operations to collect the samples necessary to ground-truth our instruments, and to distinguish the species contributing to biological layers we detect. For example, the community composition of bioluminescent plankton changes from a near-shore environment dominated by dinoflagellates and larvaceans to an offshore environment consisting of copepods and large zooplankton. Although we can detect the changes in bulk signals with AUVs, we only know the community composition as a result of long hours of sampling. In addition to being difficult to collect, these physical samples are only approximately correlated with the high-resolution sections gathered by the AUV. As we develop better instruments to distinguish the transitions in biological communities -- whether across fronts, depths, or seasons -- we are still dependent on water samples to tell us which species are responsible for the changes in fluorescence and bioluminescence that our sensors detect.

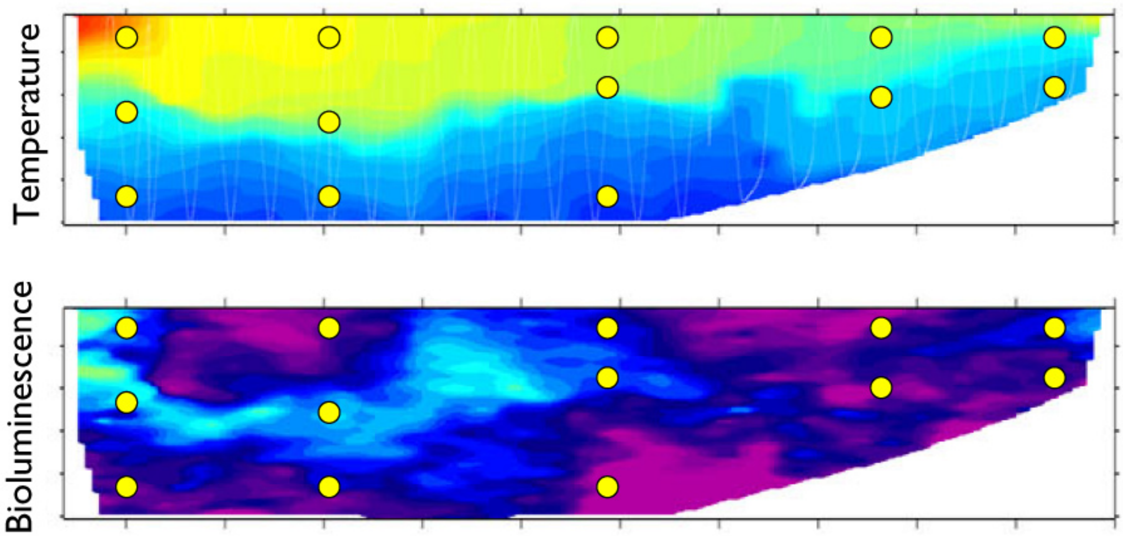

Figure 1. Example of typical AUV ecosystem / bioluminescence survey in which water samples (yellow circles) are taken from ship along the AUV transect. This method does not use the real-time information from the AUV and thus may miss some of the most pronounced features encountered by the AUV for which a water sample would be most valuable.

The addition of a water-sampling capability to the AUV would make it truly autonomous, and would enable a revolutionary type of comprehensive surveys not currently possible. Until that time, operating the AUV will continue to be more like walking a dog rather than teaching it to fetch.

Vrijenhoek Lab

Our lab is interested in understanding the processes that control larval distribution and subsequent gene flow. To develop the technology and base-line data required to detect larval invertebrates in situ, we have chosen two locally abundant species (acorn barnacle and blue mussel) in Monterey Bay. We have conducted weekly water sampling with bucket sampling (5 liters) at the Monterey Coast Guard Pier and with the Environmental Sample Processor (ESP). While these samples are critical to our research (20 total weekly samples and 8 ESP samples over a 1 year period), they provide only a nearshore picture of larval distribution. From other research, it is clear that planktonic larvae are moved offshore following spawning. In order to successfully recruit, these same larvae must return inshore to the intertidal areas to settle. Therefore, the key to understanding larval distribution in Monterey Bay (and beyond) is the spatial and temporal pattern of larvae between spawning and settlement.

From our time series data, both of our target species would be detectable in 1 liter of water. Background values of the acorn barnacle at the Monterey Coast Guard Pier are typically 40-50 individuals/liter with recruitment periods characterized by 2000-3500 individuals/liters. Our DNA probe assay used to detect larvae has a lower limit of approximately 50 individuals/liter. Therefore, in order for the AUV gulper to be beneficial to our larval ecology research, a minimum of 1 liter water sample is required. In addition, the number of samples that we would require to have adequate sampling is 6-12 samples per linear transect. This number of samples would allow us to determine the distribution of larval mussels and barnacles from the near shore to offshore. To process 12 water samples with our DNA probe assay would take approximately 6 hours. We envision (ideally) a bi-monthly sampling schedule.

We believe that water samples collected by the AUV gulper will provide us critical data that has hereto been unavailable. For example, certain species of barnacles (including our target species) accumulate in thin layers along an upwelling front. AUVs are capable of high-resolution mapping of such fronts. One of the key benefits of having the AUV collect water is the immediate proximity of the AUV to the feature of interest. With ship sampling of the front, numerous CTD casts would need to be taken to establish ones position relative to the front.

While the distance between samples might be on the order of kilometers, we require a high water collection speed (<5 sec). This requirement is due to the fact that larval distribution is patchy and could easily be missed via dilution if the AUV had to integrate water collection over a distance. Similarly, larvae are capable of evasive swimming and could be missed if the water sampling rate was too low.

The data collected from the AUV water samples would provide us with data critical to our larval ecology research. By understanding the near shore vs. offshore distribution of larvae, we can better optimize our placement and timing of ESP deployments.

Ryan Lab

Our lab applies multiplatform, multidisciplinary observation of the coastal ocean to study complex processes in Monterey Bay and adjacent waters. The AUV has been a primary platform for our research. The key advantages of the AUV that we have applied are synoptic resolution, multidisciplinary measurements, and operability around complex shelfbreak topography. Because many coastal processes of ecological significance occur on small spatial and temporal scales, they are easy to miss without high-resolution sampling. Dorado is now regularly mapping the bay ecosystem at high-resolution and examples of ecologically significant processes we simply could not see before are accumulating with this increased resolution. Further, the AUV is moving solidly toward unattended operation. If we consider two modes of AUV water sampling: 1) a prescribed profiling mode and 2) an adaptive/responsive mode, it is the adaptive mode in which we are most interested. We believe this is essential to acquire water samples at the right place and time. Below are two examples of research we would like to pursue with water sample acquisition on the AUV.

Example 1: Plankton layer ecology

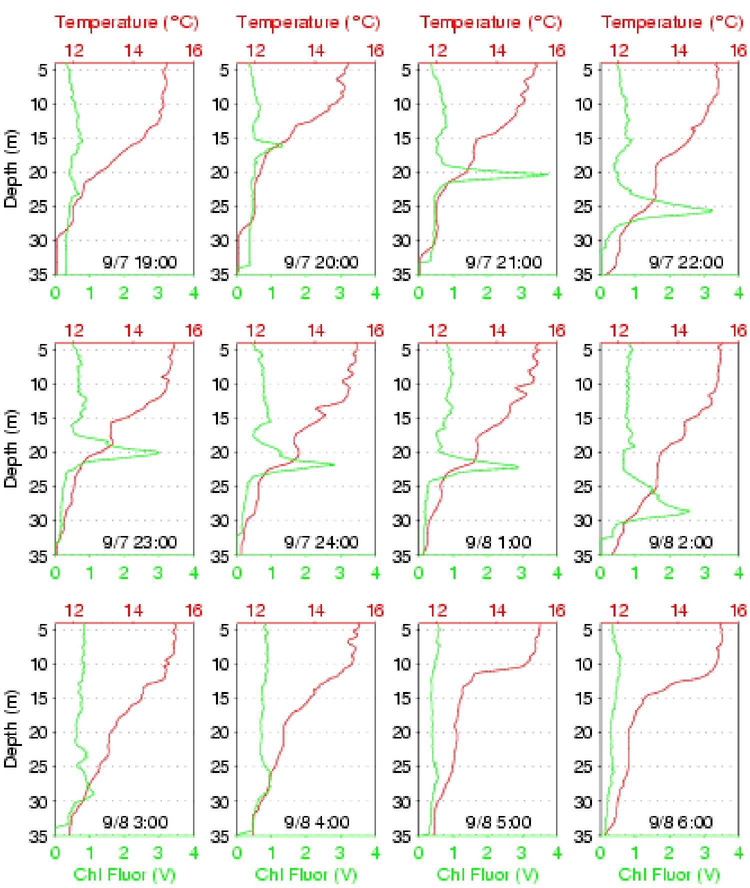

Figure 2. Time series from a vertical profiler on the northern Monterey Bay shelf during AOSN II, illustrating phytoplankton layer formation and dissipation on small spatial / short temporal scales.

Phytoplankton layers occur across a wide range of scales. In Monterey Bay we have observed layers forming and dissipating on time scales ranging from hours to days and on spatial scales ranging from 1-15 m in the vertical and a few to tens of kilometers in the horizontal. For example, last year we learned that concentrated phytoplankton layers can form and dissipate in phase with the diurnal internal tide. Figure 2 shows a sequence of hourly profiles for a 12-hour period during which the layer formed and dissipated. This pattern was repeated over four days, until the time series was ended. This example represents the finest vertical scales over which we have observed phytoplankton layers in Monterey Bay. From this time series we would define an average layer thickness of ~ 3 meters. The wind and tidal forcing related to these layers occurs commonly in this region and suggests that this scale of biological-physical interaction is basic to the Monterey Bay ecosystem. For this example we would want to sample water from above, within and below these layers to examine the vertical structure of plankton communities that form. The type of sampling we envision for layers would take advantage of the relatively large horizontal scale compared to the small vertical scale. Because the layers tend to remain within a water density range, an AUV algorithm that mapped the biological layer to density on a downcast profile could apply a density-based sample acquisition scheme to sample the layer and adjacent water on the following upcast profile.

Example 2: shelf sediment transport
With only monthly sampling along the axis of Monterey Canyon last year, large plumes of suspended particulate material were observed adjacent to the continental shelf in all three seasons of operational surveys (e.g. Figure 3). The particles were evident by their optical backscatter, and observations from *Dorado* showed that they were not photosynthetically active phytoplankton or zooplankton. Thus they were probably shelf sediments being transported off-shelf, with significant implications for ocean margin carbon flux. The project Observing Complexity in the Coastal Ocean conducted AUV surveys from the shelf and out over the shelfbreak and canyon. In multiple surveys we saw deep-shelf plumes of suspended particulates extending from the shelf and out over the canyon (smoking gun?). The last observation was during a transect from the northern inner shelf to M1, a transect that is now shared by multiple labs as a standard monitoring transect. In this case we were able to acquire data for describing the particle size spectrum of the particles, but a water sample would be essential to understand what these particles are and to quantify their transports.

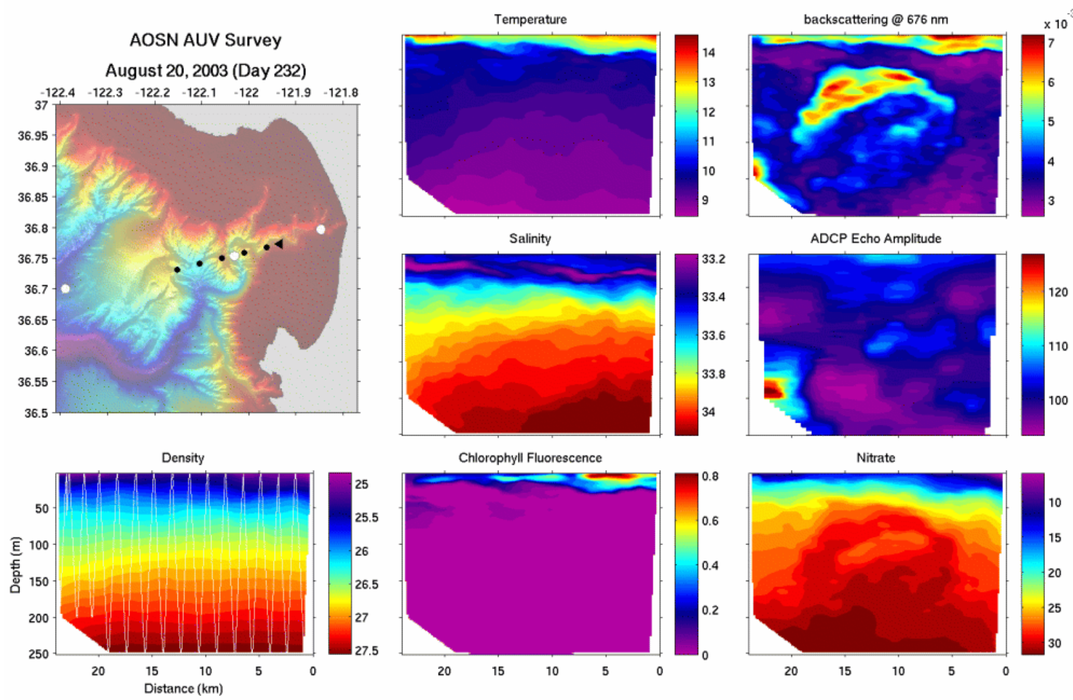

Figure 3. Canyon axis AUV survey showing probable shelf sediment plume (upper right panel).

Scholin Lab
Scholin lab interests in AUV water sampling relate to harmful algal bloom (HAB) ecology. Source populations of organisms that ultimately give rise to HABs in coastal areas may occur offshore and be subsurface, sometimes in thin layers, and therefore are often difficult to detect using traditional ship surveys and remote sensing. Efforts to study, manage, and mitigate the negative impacts of HABs demand species-level cell identification and quantification, an understanding of how blooms are driven by and/or respond to chemical and physical properties of the water column, and how toxins produced by some of these organisms propagate through the food web. The Scholin lab is finding that toxicity of *Pseudo-nitzschia australis* can vary tremendously over very small spatial scales (~10 m in the vertical, a few kms in the horizontal). Causative mechanisms emerging from recent studies involve nutrient concentrations and ratios. One example of a phytoplankton layer mapped by AUV the day before a layer abundant in *P. australis* was sampled in situ in the

same area, is shown in Figure 4. In this Odyssey IIB survey, the AUV did not have nitrate measurement, but the current operational Dorado vehicle has ISUS for nitrate measurements important to studies of nutrients and HAB toxicity.

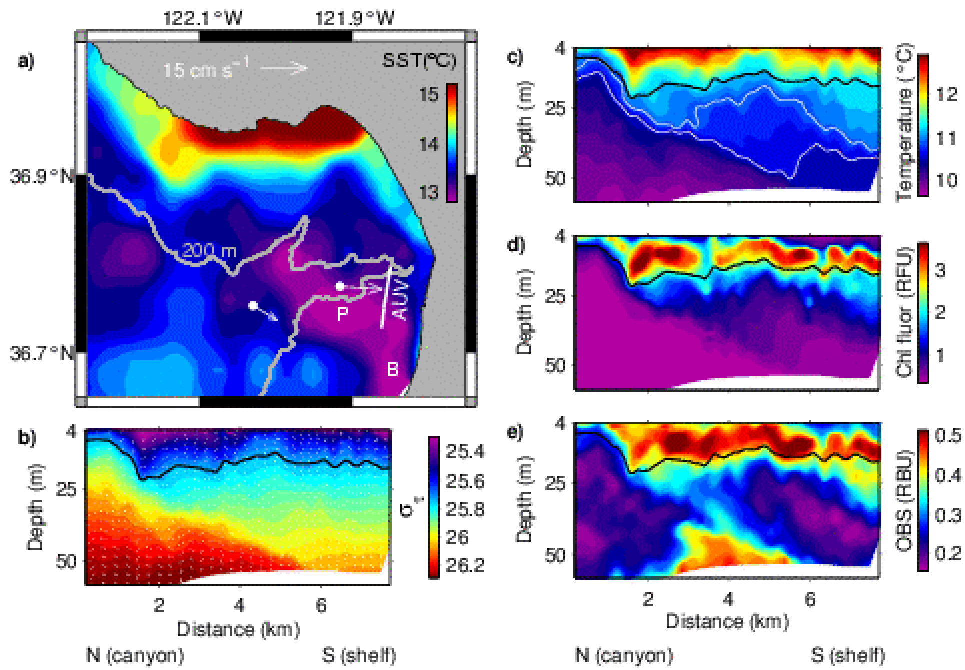

Figure 4. MUSE AUV survey showing a phytoplankton layer on the southern shelf. A profile in the same region the following day showed *P. australis* to be highly abundant in a subsurface layer, and with widely variable toxicity through the water column.

Collaboration between the Scholin and Ryan labs during AOSN II applied the AUV for adaptive sampling in phytoplankton ecology studies. In these efforts we ran an AUV vertical section, downloaded a decimated data set across the radio link to the ship, rapidly processed the data to identify and locate phytoplankton “hot spots”, and used a ship to obtain a water sample from the hot spot location (latitude, longitude, depth) targeted from the AUV survey. The water sample was then brought back to the Scholin lab for analysis of harmful algal species. In this study the AUV was providing not only the ecological context, but also the human-aided intelligence for obtaining a water sample in the right place at the right time. We would benefit greatly if AUV onboard intelligence could adaptively acquire water samples in the right place and time, e.g. in subsurface phytoplankton layers or in near-surface filaments transporting phytoplankton into or out of the bay.

Sampler Name	**Max # of samples**	**Max sample vol**	**Sample vol range**	**Design**	**Size**	**Weight**	**Sampling rate**	**Power**	**Cost**	**Notes**
EnviroTech, AquaLAB Gas-tight deep ocean water sampler	50	1L	75mL - 1L	Syringe, multi-port valve	Length = 26" Diam = 7"	Air = 39.6 lbs (plus 11 lb controller)	200cc/min	V = 13.5 VDC Ipeak = 740 mA, I (motors still) = 140 mA, Isleep = 125uA	$37k	Gas tight (titanium foil bags) 2 stroke acquisition (inhalation and pump to bag) Rated to Full ocean depth Slow Reusability of bags? Cost?
EnviroTech, AquaMonitor Smart Water Sampler	50	3L	100mL - 1L	Syringe, multi-port valve	Length = 24.5" Diam. = 5.7"	Air = 17.6 lbs Water = neutrally buoyant	200 cc/min	V = 12 VDC Ipeak = 740 mA, Imean = <2mA	$23-30k	Similar issues to Aqualab Handling issues potentially problematic
McLane Remote Access Sampler	48	500 mL	100-500mL	Pump with multi-port valve	Length = 65" Width = 17" Height = 17"	Air = 240 lbs (containers full- >325 lbs) Water = 125 lbs	75 mL/min (also have 150 mL/min pump)	31.5 VDC <1A when pumping	$27k	Heavy Expansion system = clean Collects particulates Bag reusability issues ($13/bag) Full ocean depth 25 port valve available Configurable for smaller package
Challenger Oceanic Multi-sampler	10	1L	1L	rotary and linear actuators. Flow sensor.	Length = 11.8" Diam. = 15.7"	Air = 33 lbs	4min/1L max (syringe)	12-24 VDC at 2A max	~$10k	Hard bottles (not as clean) Fewer samples (may need >1) Small Single stroke acquisition More mechanically complex Simple control input Could put together bag/valve/pump system Much faster sampling if there is no filter
Chelsea Technology group, Autonomous Plankton Sampler (Collects particles)			Uses standard 270 um mesh silk or 80 um nylon gauze	Updated Hardy mechanism	5.5" x 9.25" x 11.5"	28.1 lbs	Can operate in towed vehicle at 25 knots	6 x 1.2v cells	$18k	Just collects particles May be good solution for those wanting large volumes