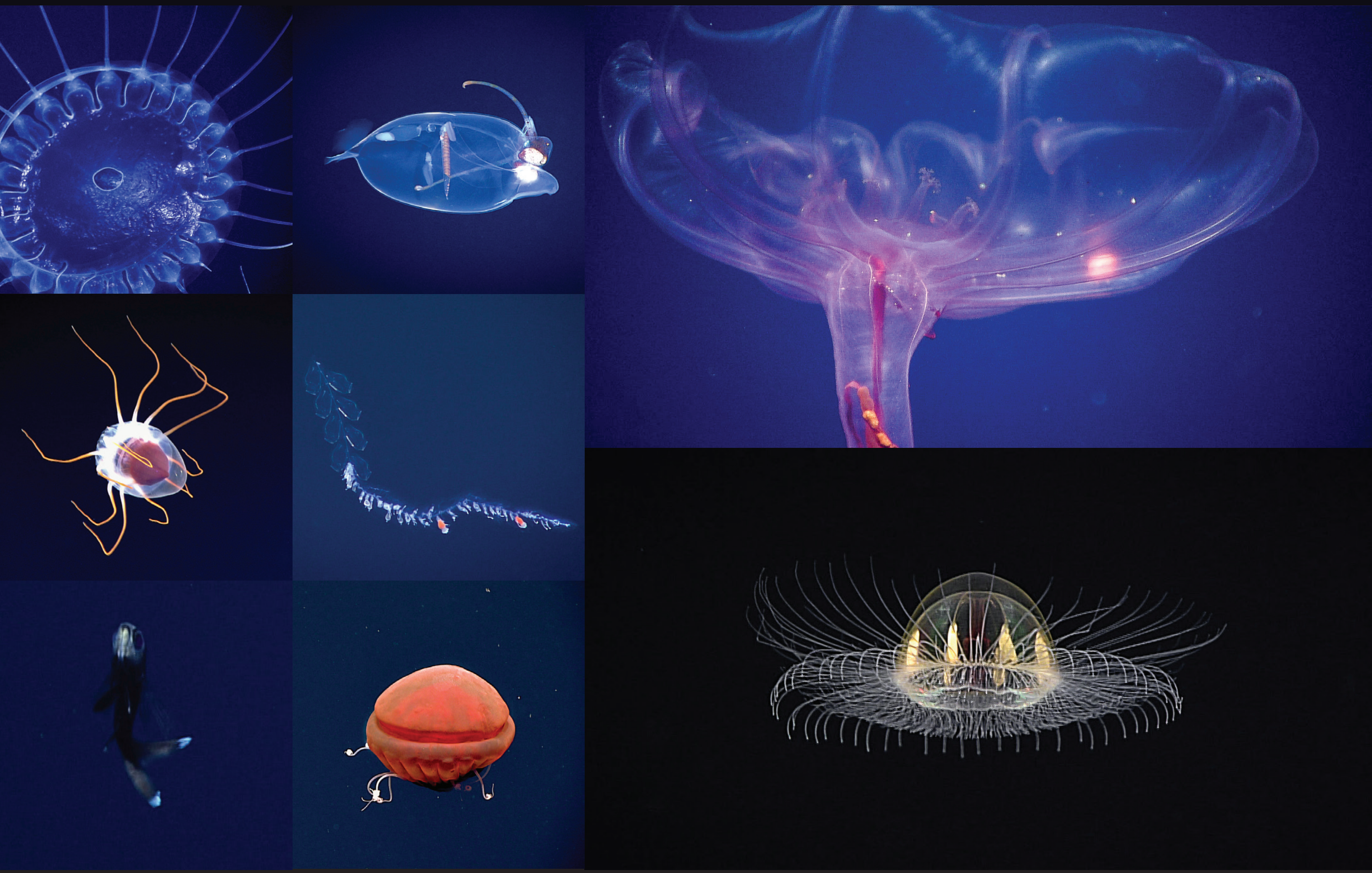
# From Surface to Seafloor

## Exploration of the Water Column

March 4-5, 2017



U.S. Department of Commerce
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Ocean Exploration and Research

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Workshop Report


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# Executive Summary

Over the last decade or so, spurred by issues such as climate change, growing reliance on both living and non-living marine resources, and heightened recognition that important, large-scale ocean environmental conditions are in states of flux, various agencies and institutions have been increasingly motivated to explore the still vastly unknown global ocean. While progress is being made toward the goal of achieving an initial regional - and ultimately global - characterization of the ocean's physical, chemical, and biological environments, a critical gap remains in characterizing the state and dynamics of the water column from the sea surface to the seafloor.

With the objective of creating an initial framework to address a multitude of knowledge gaps about water column environments, NOAA's Office of Ocean Exploration and Research (OER) hosted the workshop, *"From Surface to Seafloor: Exploration of the Water Column."* The workshop took place on March 4-5, 2017 in Honolulu, HI, and was attended by 47 scientists, engineers, and program managers. Florida Atlantic University's Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) co-hosted the event. This report summarizes the outcomes of the workshop, and provides guidance to researchers, program managers, foundations, and agencies to mobilize resources to best meet the challenges of fully characterizing the three-dimensional ocean.

In the first part of the workshop, the main scientific questions and knowledge gaps pertaining to the water column were distilled into 5 themes: (1) What lives in the water column? (2) How is the water column structured? (3) What are the anthropogenic influences on its natural variability? (4) Do we know what we don't know? (5) How do we get people to care? Geographic priorities identified included unexplored regions, areas undergoing significant current or expected future anthropogenic changes, biological hot spots, environments in close proximity with contrasting characteristics, and areas where the adjacent seafloor is relatively well-explored.

In order to comprehensively characterize the water column, temporal reconnaissance is required and a multidisciplinary "toolbox" of sensors, instruments, and techniques must be employed. Collaborations should be developed to allow for opportunistic data collection on ships, long-term observing networks, ROVs, and autonomous platforms in order to collect ancillary water column data wherever and whenever possible. This report outlines types of underway and station data that could augment hydrographic and geological cruises of opportunity, provides detailed guidance on best practices for operating various types of ROVs in the midwater, and suggests how existing long-term observing networks can be leveraged with biological and deep-mounted sensors to collect temporal reconnaissance data to inform adaptive and intensive ship-based sampling. Any leveraged data collection program will require a champion individual or institution to coordinate and ensure consistent and high-quality data are collected and made accessible among all participating programs.

A proposed water column exploration program of the future would be comprised of six components: (1) continual refinement of seminal questions and key regions, (2) reconnaissance from long-term research monitoring tools, (3) technology development guided by the seminal questions, (4) dedicated midwater cruises with intensive sampling, (5) improvements to sample processing, data management, and analyses, and (6) contribution to a global rapid response network.

OER has already begun implementing some of the recommendations of the workshop by facilitating enhanced communication within the water column exploration community, funding water column related projects through the OER's annual Federal Funding Opportunity, and conducting midwater ROV dives with improved analysis and reporting of CTD and water column acoustic data on NOAA's dedicated ship of ocean exploration, the *Okeanos Explorer.* Achieving the vision of a comprehensive, multi-institutional, and interdisciplinary water column exploration program will require investment now in novel technologies, strong interagency coordination, and innovation and maintenance of an exploration fleet comprised of various seagoing assets.

# Contents

# I. Workshop Overview

NOAA's Ocean Exploration and Research (OER) program began in 2001 with the overarching goals of exploring unknown and poorly known ocean areas, discovering and investigating understudied ocean phenomena, and facilitating research to inform marine resource management. OER efforts have mostly been focused on exploring deep benthic environments, and although the water column is the largest contiguous habitat for life on this planet, most of this realm remains unknown. Seeking to address vast knowledge gaps concerning the pelagic environment, OER is pursuing multi-agency and multi-institutional initiatives to expand exploration in the water column. On March 4-5, 2017, physical, chemical, and biological oceanographers and ocean technologists attended a workshop dedicated to the development of coordinated open ocean exploration during the next decade. This workshop was co-hosted with Florida Atlantic University's Cooperative Institute for Ocean Exploration, Research, & Technology at the University of Hawai'i, Mānoa immediately after the 2017 ASLO Aquatic Sciences Meeting.

The primary goals of the Surface to Seafloor workshop were to:

- Outline priorities for water column exploration and research
- Identify best practices for obtaining high-quality, high-resolution data in the water column that address these research priorities
- Expand the capacity of the "exploration fleet," typically focused on seafloor mapping and ROV surveys, to make water column measurements and observations
- Collect input on innovation and integration of relevant technologies (e.g., sensors, platforms, instruments) for water column exploration
- Encourage collaborations for ongoing and future efforts in water column exploration and research

The workshop agenda can be found in **Appendix 1** and a participant list in **Appendix 2**. More information, including background materials, is available at:
http://oceanexplorer.noaa.gov/fsts/.

# II. Introduction to the Water Column

### Science Overview

The "water column" constitutes the full volume of water in the ocean, spanning from the ocean's surface to the seafloor interface. Organisms that live throughout the water column are critical to biogeochemical cycles. For example, many zooplankton and nekton transfer carbon to the deep ocean via diel migration between the surface layer and the mesopelagic zone and/or by the production of fecal material that sinks. Furthermore, deep-pelagic fauna are major consumers of global marine plankton production, and are themselves key prey of higher trophic-level organisms, including squids, marine mammals, seabirds, and some commercially-exploited fishes. Several studies using active acoustic data have demonstrated that biomass of mesopelagic fishes is likely an order of magnitude higher than was estimated in the 1980s based on trawl catches[1,2], and in situ investigations have revealed that gelatinous zooplankton are far more abundant and critical to marine food webs than recognized using trawl and acoustic means.[3]

Marine microbes are extremely numerous throughout the water column, and bacteria and archaea dominate energy flux and cycling of biologically-important chemical elements. Viruses are ten times more abundant in the ocean than bacteria and archaea and scientists are just beginning to uncover the roles of viruses and archaea in marine ecosystems. In the last two decades, ocean exploration - including DNA sequencing - has revealed immense biodiversity of marine microbes, including chemosynthetic microorganisms in hydrothermal plumes. Ongoing improvements in capabilities to retrieve and culture marine microbes in situ and in conditions that mimic their natural habitat will provide opportunities to gain a more mechanistic understanding of the great diversity of microbes in the ocean.

There is a high degree of interaction between the epipelagic (0-200 m), mesopelagic (200-1000 m), bathypelagic (2000-4000 m), and abyssopelagic (4000-6000 m) depths, with recent discoveries suggesting these canonical discrete pelagic zones may be obsolete. For example, some "epipelagic" predators, such as marine mammals and white sharks, are known to dive to over 1000 m and some "mesopelagic" predators have been shown to feed broadly across epi-bathypelagic waters[4]. Further, it appears there may be little difference between bathypelagic and abyssopelagic assemblages. Features such as clines, plumes, bottom topography, and fronts likely define biological boundaries more than do the traditional depth-based designations of the pelagic zones. Major advances currently underway that are expanding understanding of biodiversity and ecology of marine organisms include genetic barcoding for taxonomy, food web studies using stable isotope analysis, and forecast modelling to inform targeted sampling associated with various oceanographic environments.

Finally, there remain significant gaps in understanding of physical and chemical

1 Kaartvedt et al. 2012. MEPS 456:1-6. doi: 10.3354/meps09785. (and refs therein)

2 Gjøsaeter & Kawaguchi. 1980. FAO Fisher. 193 pp.

3 Robison, B.H. 2004. Deep Pelagic Biology. J Exp Mar Biol and Ecol 300:253-272. doi:10.1016/j.jembe.2004.01.012.

4 Choy et al. 2013. MEPS 492:169-184. doi: 10.3354/meps10518.

oceanography of the deep open ocean. With a few exceptions, such as the World Ocean Circulation Experiment (WOCE)[5] and GO-SHIP[6], deep measurements of physical parameters are rare. Similarly, challenges to obtaining high-quality chemical measurements hinder their widespread collection. The GEOTRACES project[7], with its focus on studying biogeochemical cycles of trace elements, has resulted in several major discoveries, revealing the basin-wide impacts of hydrothermal vent-derived iron and the extent of mercury contamination throughout the ocean **(Fig. 1)**.

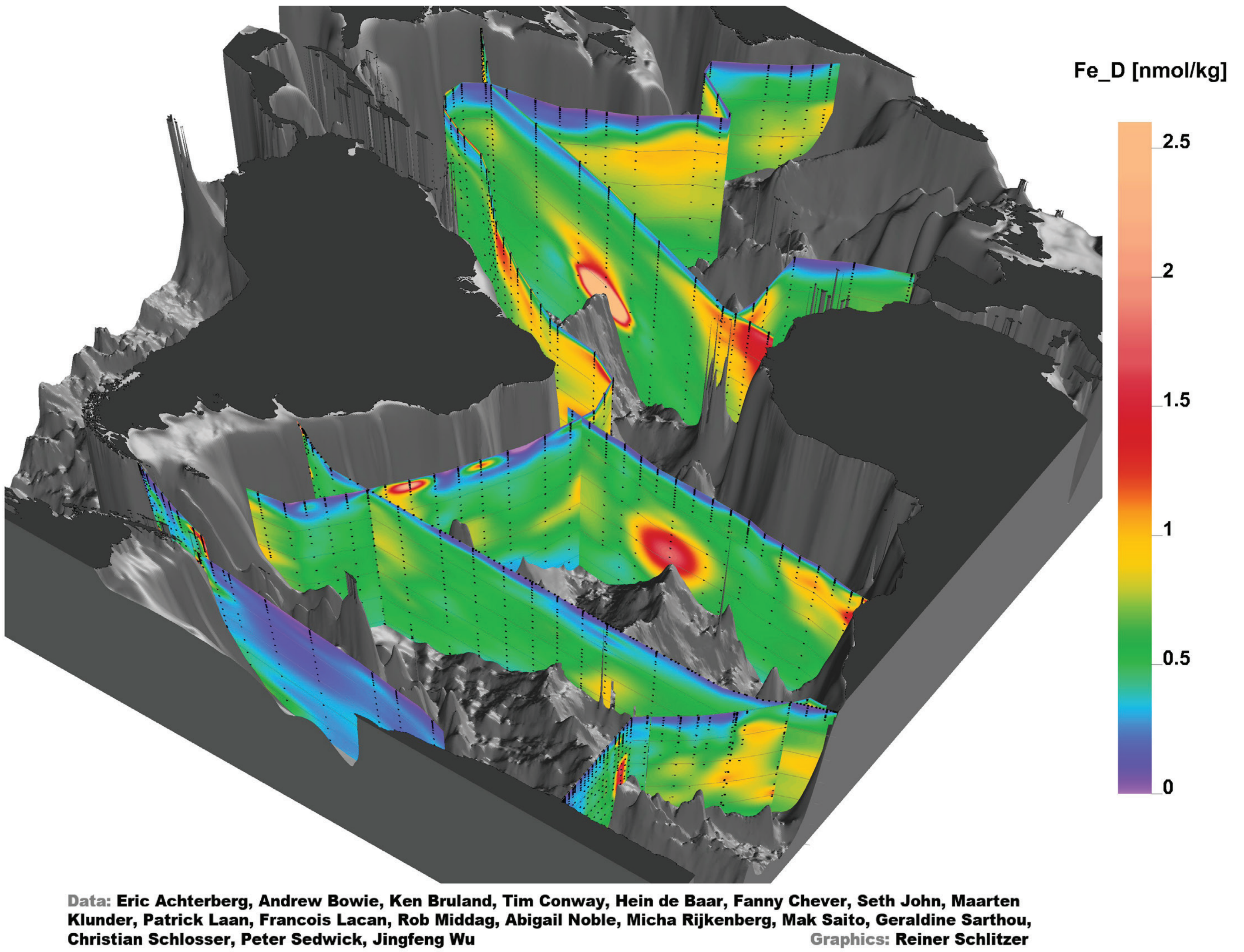


**Figure 1.** Basin-wide measurements of iron have revealed the role of hydrothermal vents as significant sources of iron into the oceans.

Some key areas for further study in marine chemistry include distribution of micro-nutrients, biological consequences of deep iron input at hydrothermal vents, and impacts of changing oceanic carbonate chemistry on organismal behaviors and species distributions.

5 https://www.nodc.noaa.gov/woce/wdiu/
6 http://www.go-ship.org
7 http://www.geotraces.org

## History of water column exploration in the U.S.

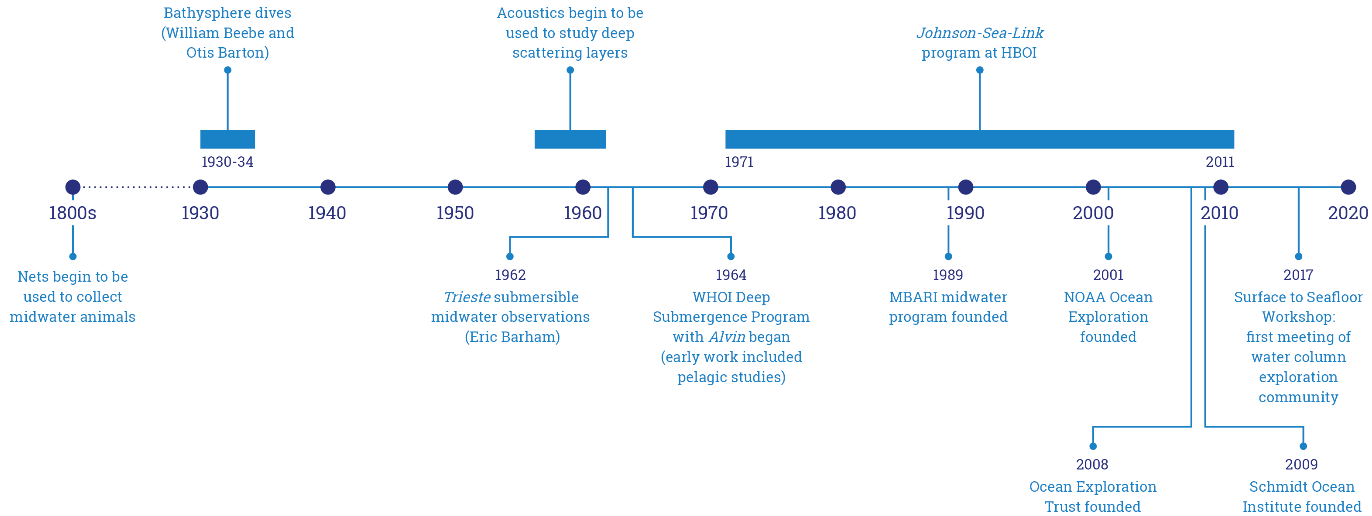


**Figure 2.** Timeline of notable events in the history of water column exploration in the United States.

Trawl nets have long been the principal means for studying pelagic animals **(Fig. 2)**. The advent of active acoustics in the 1950s and 60s expanded studies of vertical distribution patterns, but both nets and acoustics are inadequate for describing temporal, spatial, and behavioral relationships. The first deep submersibles operated in the 1930s were used to observe pelagic fauna, but subsequent submersible developments focused on the seafloor, with only sporadic advancements for midwater research (e.g., Eric Barham's dives in the 1960s and the *Johnson-Sea-Link* program in the 1970s to early 2000s). Direct access to the deep sea has broadened understanding of deep pelagic ecology by facilitating observations of animal behavior, enabling collections of live specimens in pristine condition, conducting manipulative experimentation, and assessing community composition of fragile pelagic organisms. Recent progress has benefited from improved imaging, new instrumentation, evolving platforms, and software developments.

### Ocean Exploration Infrastructure

There are several contemporary oceanographic programs that stand out with missions dedicated to exploration, including significant telepresence and outreach components:

A. **Woods Hole Oceanographic Institution (WHOI) National Deep Submergence Facility**
The WHOI Deep Submergence Program began in 1964 when the human occupied vehicle (HOV) *Alvin* was built; midwater biologists and continental margin geologists were the primary early users of *Alvin*. Over time, there was a demand for vehicles that could stay longer, dive deeper, cost less, and remain safe. This demand led to the development of remotely operated vehicles (ROVs) both within the Deep Submergence Program[8] and around the world.

B. **Monterey Bay Aquarium Research Institute (MBARI)**
In the 1980s, a team at the University of California Santa Barbara used 1-person

8 Fornari, D. 2004. Oceanus. 42(2):20-24. http://www.whoi.edu/oceanus/feature/realizing-the-dreams-of-da-vinci-and-verne

submersibles to conduct midwater exploration. This effort morphed into an ongoing (>25 years) ROV-based midwater research program at the Monterey Bay Aquarium Research Institute[9]. MBARI was founded in 1987 with a mission to be a world center for advanced research and education in ocean science and technology. Funded by the David and Lucille Packard Foundation, MBARI emphasizes the peer relationship between scientists and engineers. ROV innovations developed there include single body operations, a variable-ballast system, modular toolsleds, midwater proficiency, swing arms, collecting and surveying methods, the Video Annotation and Reference System (VARS), and more. MBARI has conducted the only mesopelagic time series of quantitative video transecting. MBARI has developed numerous other instruments for water column exploration, including gliders, autonomous underwater vehicles (AUVs), and the i2MAP system which was recently developed to automate midwater transects.

### C. NOAA Ocean Exploration and Research (OER) and the Ocean Exploration Trust

Launched in 2001, NOAA OER[10] is the only federal organization dedicated solely to exploring the unknown ocean. OER executes this mission through exploration expeditions on NOAA Ship *Okeanos Explorer* and through competitive grants for exploration and research. "America's Ship for Exploration," *Okeanos Explorer* is equipped with a suite of acoustic instruments, CTD and oxygen sensors, and the 2-bodied ROV *Deep Discoverer*. Since 2015, the *Okeanos Explorer* has been conducting community-driven opportunistic midwater transects associated with seafloor surveys. NOAA OER also provides support for, and partners with, the Ocean Exploration Trust[11], which operates the Exploration Vessel *Nautilus*. The key goal of their program is to visit areas of the ocean that have never been explored. Hallmarks of both OER and OET include strong marine science and technology community participation through leveraged collaborations.

### D. Schmidt Ocean Institute

The Schmidt Ocean Institute (SOI)[12] was founded in 2009 to provide grants for shiptime, technology, and technology support on the R/V *Falkor*, including midwater research. R/V *Falkor* is equipped with the 4500 m-capable ROV *SuBastion*, a full sonar suite, telepresence capabilities, and shipboard high-performance computing for at-sea modeling and data analysis. SOI's outreach programs include communications training for all PIs, the Artist-at-Sea program, student opportunities at sea, and a near real-time web-based video annotation system for citizen scientists.

## Community Guidance

Over the last two decades, there have been several efforts to solicit guidance on the future of deep submergence programs in the US, including consideration of the water column. These include (with references to relevant reports):

9 http://www.mbari.org
10 http://oceanexplorer.noaa.gov
11 http://www.oceanexplorationtrust.org
12 https://schmidtocean.org

1. Submersible Science Study (1990) - UNOLS[13]
2. Undersea Vehicles and National Needs (1996) - National Research Council[14]
3. DEveloping Submergence SCiencE for the Next Decade workshop (DESCEND, 1999)[15]
4. Discovering the Earth's Final Frontier (2001) - Report of President's Panel[16]
5. Future Needs in Deep Submergence Science (2004) – National Research Council[17]
6. Critical Challenges for 21st Century Deep-Sea Research (2015)- European Marine Board[18]
7. DESCEND 2 workshop (2015)[19]

In general, the traditional emphasis on benthic research has diminished the opportunities for - and thus interest in - water column research. At the most recent of these workshops, DESCEND 2, the participants identified key questions, logistical challenges, and cultural impediments to water column exploration. Recommendations for addressing all of these challenges and opportunities included enhancing partnerships and communication, developing specialized deep submergence vehicles for midwater research, and investing in autonomous midwater vehicles capable of sustained observations and sampling.

Most recently, the 2016 National Academies Keck Future Initiatives (NAKFI): Discovering the Deep Blue Sea meeting[20], was a nontraditional meeting of artists, scientists, engineers, and others intended to foster novel collaborations through a grant development process. The identification of the deep pelagic as a focal topic of the 2016 NAKFI meeting reflects a growing appreciation of the significance of the pelagic realm at the national level.

The OER Surface to Seafloor workshop has built upon these efforts to stimulate partnerships and rekindle communication within the water column exploration community, refine the knowledge gaps, and provide a framework for initiating a multi-institutional water column exploration program.

13 https://www.unols.org/sites/default/files/199011des_searchable_lo_res.pdf
14 https://www.nap.edu/catalog/5069/undersea-vehicles-and-national-needs
15 https://projects.iq.harvard.edu/files/descend2/files/descend_workshop_1999_proceedings_.pdf
16 https://oceanexplorer.noaa.gov/about/what-we-do/program-review/presidents-panel-on-ocean-exploration-report.pdf
17 https://www.nap.edu/catalog/10854/future-needs-in-deep-submergence-science-occupied-and-unoccupied-vehicles
18 http://www.marineboard.eu/sites/marineboard.eu/files/public/publication/EMB_PP22_Web_v4.pdf
19 https://descend2blog.wordpress.com/descend2-draft-reports/
20 https://www.keckfutures.org/grants/deep_blue_sea_grantees.html

# III. The Unknown Water Column

## Critical questions in the water column

**What are the main scientific questions/gaps relating to the water column?**
The main scientific questions and knowledge gaps pertaining to the water column were distilled into five themes (see **Appendix 3** for a detailed list of questions):

1. **What lives in the water column?**
   The questions in this category are centered around understanding biodiversity, biogeography, ecology, and behavior of pelagic animals.
2. **How is the water column structured? Do the different zones need to be redefined?**
   These questions regard the physical and chemical properties of the water column, energy flux, and connectivity between zones.
3. **What are the anthropogenic influences or natural variability?**
   How are pelagic animals affected by climate change, nutrient inputs, and pollutants in the marine environment?
4. **Do we know what we don't know?**
   Only in recent decades have we learned about the microbial loop, abundance of gelatinous animals **(Box 1)**, and the high biomass of fishes in the water column. This set of questions focuses on the likely existence of other unknowns for which we do not even yet know the questions to ask **(Box 2)**.
5. **How do we get people to care?**
   This section focuses on how to communicate the importance of the water column to the public and ocean policy makers.

**Box 1. The Unknown Gelatinous Fauna**
by Dhugal Lindsay and Russ Hopcroft
Perhaps the least well-known inhabitants of the ocean's vast midwater realm are the gelatinous forms, including classical jellyfish, comb jellies (ctenophores), sea tadpoles (larvaceans) and colonial siphonophores. For the vast majority of these animals the only thing we know about them is that they exist, and the original descriptions are often the only published information on any given species. Sporadic sightings by submersibles provide additional, albeit limited, distribution data. Because many of these animals are mangled or extruded into gelatinous spaghetti through the meshes of standard plankton nets, quantitative data are missing, as well as basic information on prey, reproductive cycles, and a host of other parameters necessary to assess the form and extent to which they impact the biology and geochemistry of our oceans. The damaged nature of most retrieved specimens also means that much of their cryptic diversity remains obscured, with a recent study splitting a single species into three separate families based on combined morphological and molecular evidence gained from submersible-caught specimens[1]. Clearly, in situ methods can enable significant new investigations of this fauna, which has been estimated to comprise at least a quarter of pelagic biomass[2].

1 Lindsay, D.J. et al. 2017 Mar Biol Res. 13(5): 494-512. doi: 10.1080/17451000.2016.1268261.
2 Robison, B.H. 2009. Conserv Biol. 23: 847–858. doi: 10.1111/j.1523-1739.2009.01219.x.

### Geographical priorities for water column exploration

Due to MBARI's sustained presence - and years of innovative water column technology development - in Moss Landing, California, Monterey Bay's water column is one of the best explored bodies of water in the global ocean. Unfortunately, comparatively speaking there has been so little work done to explore the water column throughout the rest of the world's ocean that exploring nearly anywhere is likely to make a significant contribution to the field. The Monterey Bay continues to be a valuable place to test instruments and methods and conduct long-term observations because of ease of access and the available data for comparison and calibration.

Priority areas to explore the water column include:

1. **Unexplored regions**, such as the polar regions, the South Pacific Gyre, the Indian ocean, and hadal depths in all parts of the ocean.
2. **Areas undergoing significant current or expected future anthropogenic changes.** Two good examples are the Arctic, a region experiencing rapid effects from climate change, and the Clarion-Clipperton Fracture Zone (CCZ), where an area nearly the size of the continental US is leased for exploration for future manganese nodule mining.
3. **Biological hot spots.** Examples include the North Pacific Transition Zone/Chlorophyll Front where there are aggregations of megafauna, mid-ocean ridges, oxygen minimum zones, and hydrothermal plumes.
4. **Contrasting environments** that are in close proximity to each other, such as the Seas of Japan and Okhotsk or the Sulu and Celebes Seas.
5. **Areas where the seafloor is relatively well-explored**, in order to achieve a fully-explored "cube," a 3-dimensional space from the surface and inclusive of the seafloor. Examples include the Gulf of Mexico and the Atlantic Ocean off the southeastern U.S. states.

**Box 2. Hadalpelagic**

by Jeff Drazen

At ocean depths of ~6,000 to 11,000 m, the hadal environment consists primarily of trenches, where crustal plates collide and one descends beneath the other. The hadalpelagic zone is one of the least explored habitats on Earth, even within the largely unexplored deep sea, because it so challenging to sample at these depths. The hadalpelagic likely harbors some of the greatest unknown biodiversity on Earth, with unique organisms highly-adapted for living at high pressure and cold temperatures. Early studies of this zone used benthic trawls and dredges pulled at very slow speeds, and many attempts at sampling resulted in the wires breaking under their own weight. The only comprehensive survey of hadalpelagic macrofauna is a single study conducted decades ago (Vinogradov 1962). Vertical midwater plankton tows were conducted in a few Pacific trenches to depths of 8,000 m. Zooplankton biomass declined with depth into the trench such that hadalpelagic zooplankton biomass was ~0.1% of surface biomass. The water column connects the hadal zone to the upper water column and to populations on the surrounding plain, suggesting that hadalpelagic studies will help us better understand the structure and function of marine ecosystems overall. Future work should pursue the use of hadal-rated ROVs, water column profilers, and trawls conducted with new synthetic fiber cables to enable exploration of these communities and their environment.

# IV. Data Needed To Explore Patterns And Processes In The Water Column

### Baseline Characterizations

A key tenet of OER's program has been to provide initial baseline characterizations of ocean environments. Baseline characterization in the context of the seafloor has been motivated by the question: "If you could only visit a site in the ocean once, what is the most critical information that you would need to characterize that site?"

On the seafloor, baseline characterizations have been constructed primarily through multibeam seafloor mapping and ROV surveys. So, what is a "baseline characterization" in the context of the water column?

### Baseline Characterization = Reconnaissance

The workshop participants interpreted baseline characterization for the water column as meaning:

1. What is the basic information required to determine the value and priorities for further work at a site or region?
2. What is the basic composition of the midwater community in a region and how is it distributed relative to water column hydrography?

Because water column features change on short temporal and spatial scales, sampling should be designed to assess the temporal and spatial variability at a site. At minimum, paired day-night sampling would provide invaluable data to compare variations in distribution patterns and behaviors due to diel vertical migration (DVM). A more in-depth approach may be to conduct long-term observations at a stationary site (e.g., using moorings) as reconnaissance to inform where and when to conduct intensive ship-based sampling.

### Use a Toolbox

The general consensus of the attendees was that exploration of the water column requires a standardized, readily available, and comprehensive set of tools.

### Toolbox for Water Column Exploration

| | Measurement | Platform/Sensor/Sample Type Required |
|---|---|---|
| | **Physical/Chemical** | |
| First tier | Basic Hydrography- temperature, density, salinity, oxygen | CTD with oxygen sensor |
| First tier | Chla Fluorescence | Fluorometer |
| First tier | Bathymetry | Multibeam sonar (1st), Side Scan sonar (2nd) |
| First tier | Irradiance/Light scattering | Light scattering sensor |
| First tier | Light Transmission | Transmissometer |
| First tier | Ocean color, SSH, temp, etc. | Imaging satellites |
| Second tier | Macro- and micronutrients/metals | Water |
| Second tier | DIC, POC/POM, pH/alkalinity | Water |
| Second tier | Dissolved gases | Water |
| Second tier | Currents | Acoustic Doppler Current Profiler (ADCP) |
| Second tier | Methane | Water |
| Second tier | Hydrogen | Water |
| Second tier | Resuspended sediment | Video, Water, Transmissometer |
| Second tier | Small-scale turbulence | Aquadopp® Profiler |
| | **Biological - single cell** | |
| First tier | Genomics | Water, Tissue samples |
| First tier | Single-cell imaging/sorting | Flow Cytometer |
| Second tier | ChlA/accessory pigments | Water |
| Second tier | Biological rates | Water |
| | **Biological - multicellular** | |
| First tier | Specimens for physiology, morphological ids, genomics | Net trawls (mult. sizes), including optical tools |
| First tier | | ROV for fragile organisms |
| First tier | In situ imaging | ROV, AUV (e.g., i2MAP), Low-light imaging, Microscopy |
| First tier | | Video Plankton Recorder, In Situ Ichthyoplankton Imaging System |
| First tier | High resolution biological "mapping" | Active acoustics |
| First tier | Bulk biodiversity | eDNA/Metabarcoding- from split net tow and water samples |
| Second tier | Food web analysis | Animal specimens (ROVs, nets) |
| Second tier | Biological rates | Animal specimens (ROVs, nets) |
| Second tier | Tracking of large animals | Hydrophone, Surface observations (megafauna) |
| Second tier | Bioluminescence | Splat screen, Low light camera, Photometers |
| Second tier | In situ responses | In situ experiments- light, metabolism, predation, flux |

**Table 1.** The darker blue shading indicates first-tier priorities that should be measured on every expedition. The lighter blue denotes second-tier priorities that should be collected whenever possible, and on more intensive missions.

**Table 1** lists the data needs identified to address the critical water column questions and make baseline characterizations. Data on all first-tier variables should be collected when operationally feasible. First-tier physical and chemical variables can all be collected using standard existing sensors. For viruses and organisms from single-cellular (bacteria, archaea, protists) to multicellular (invertebrates, vertebrates), collection is mandatory for conducting morphological and genetic identifications, to study physiology, and to assess trophic interactions. For single-celled animals, collection of water with Niskin bottles, in situ filtering, or flow cytometry is required. Net and ROV sampling remain essential to obtain most multicellular animals. Quantitative video surveys should be used to study deep-pelagic fauna to investigate small-scale distributions and animal behavior (See Appendix 4 for detailed recommendations on video surveys using ROVs). A promising autonomous system for such surveys is the MBARI i2MAP AUV[21]. Acoustics constitutes a powerful means to collect high spatial- (e.g., shipboard or vehicle-based acoustics) or temporal- (e.g., moored echosounder) resolution data on distributions of some midwater organisms. Most animals remain acoustically indistinguishable, so these data are most useful for identifying aggregations and guiding other sampling mechanisms. Environmental DNA (eDNA) metabarcoding is being developed for biomonitoring of the presence and relative abundances of pelagic animals. Though still requiring specialized labor, the use of eDNA is revolutionizing the temporal and spatial scales for surveys of biodiversity because the presence of organisms can be identified with only a water sample.

### Challenges

Challenges remain to optimizing collection, management, and analysis of data required to address critical questions and characterize midwater environments. Capabilities to collect and store large quantities of data have rapidly increased, however quality controls and data analyses remain time-intensive to implement. Data quality, storage, sharing, and serving are particularly critical for a national shared resource like NOAA Ship *Okeanos Explorer*. Several ongoing programs exist to address metadata standards (e.g., video data[22]), however data quality must be consistently maintained and decisions made about how best to serve data (e.g., raw v. quality controlled). Because exploration is often conducted with input from multiple researchers (versus a traditional funded-PI model), it is essential that workflows be implemented to ensure that post-survey data analysis is conducted in a timely manner. For example, annotating a single video survey can take days or weeks. Automated routines for serving and analyzing data could address analysis backlogs. Automated analyses are already in development or available for some image and genetic datasets, however they are not standardized nor are they routinely implemented The community should continue to improve autonomous systems for data collection, e.g., flow-through systems and autonomous underwater vehicles with attention given to increasing battery power, reducing biofouling, and addressing maintenance requirements. Finally, communication and coordination are essential to the success of a multi-stakeholder initiative. Given the interdisciplinary explorations envisioned, the stakeholders must agree on priorities and protocols to achieve the stated goals. Confronting the challenges of data management and analysis, automation, and communication all requires investments of time and money.

21 http://www.mbari.org/technology/emerging-current-tools/video/i2-map/

22 https://github.com/underwatervideo/UnderwaterVideoWorkingGroup/blob/master/Meetings/2016_Workshop/Documents/FINAL-2016VideoWorkshopReport.pdf

# V. Opportunistic Data Collection

In response to the question, “How can existing assets and opportunities be leveraged to provide the data needed to address exploration and research priorities for the water column?”, the Surface to Seafloor workshop participants were challenged to propose opportunities to leverage a range of existing oceanographic programs and platforms to meet the requirements of water column characterization.

### Hydrographic and Geological Cruises

Hydrographic cruises survey swaths of ocean basins to collect a wide array of oceanographic data. Because these cruises regularly transit largely unexplored regions of the ocean, they are ideal programs for effective leveraging to collect reconnaissance data for water column exploration objectives. Collaborations could be developed to supplement the instrumentation and data collection on these cruises to collect critical water column data, particularly with respect to biology, which is often neglected in such surveys.

Underway systems that do not add additional time to a cruise should be operated to provide high quality data. These include fisheries echosounders, multibeam echosounders, and ADCPs. Towed passive acoustic systems could also be deployed during transits. Whenever cruises include deployment of CTD rosettes, they should be augmented with as many of the recommended sensor and imaging systems as practical and possible (**Table 1**, also see GO-SHIP[23] and GOOS Essential Ocean Variables[24] data requirements). Flow-through water systems can be used during transits to obtain temperature, salinity, carbon system parameters, optical properties, nutrients, and anthropogenic inputs (plastics, mercury, etc.). Multibeam seafloor mapping cruises, especially when going to unexplored regions of the ocean, could be leveraged with additional sea time whenever practicable in order to conduct CTD casts and collect other water column measurements. Further, all water column multibeam data should be QA/QCed and saved. Geological expeditions to conduct drilling or coring operations could make use of the descent through the water column by adding sensors and cameras to their instruments to collect some opportunistic data in the midwater. To successfully collect quality ancillary data will require meticulous coordination regarding stewardship of the instruments and data quality control and delivery.

23 http://www.go-ship.org/DatReq.html
24 http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

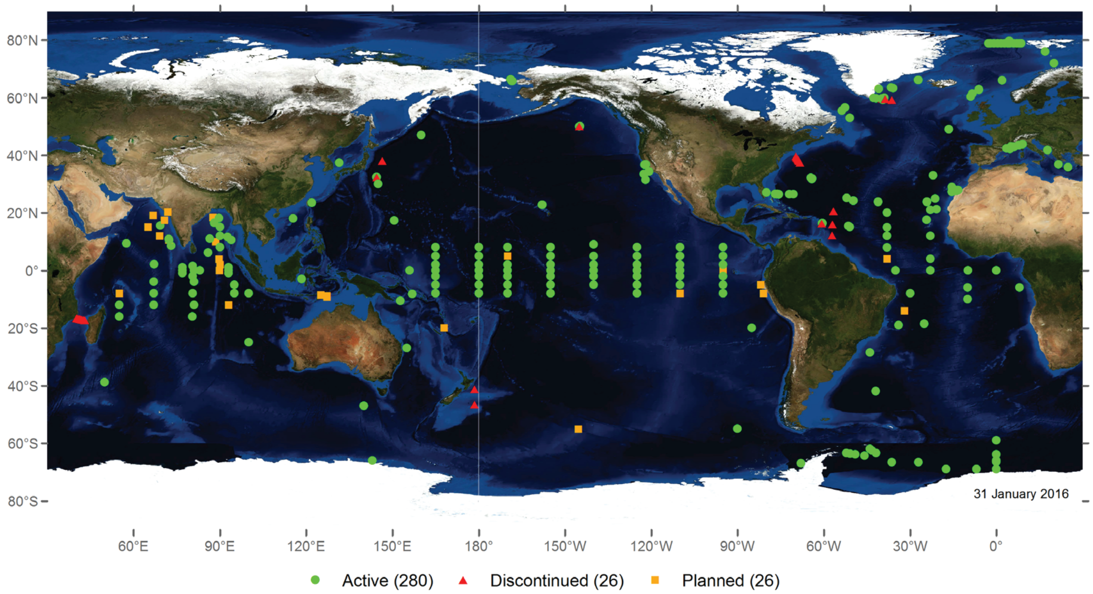


**Figure 3.** Map of long-term, open-ocean reference stations. OceanSITES typically aim to collect multidisciplinary data from the full depth of the water column.

## Long-term Observation Networks (LTONs)

Long-term observing networks (LTONs) operate on both ship-based (e.g., HOTS, BATS, and CalCOFI) and non-ship platforms. The latter include deep ocean profiling floats (e.g., Argo), and stationary platforms such as traditional moorings (e.g., OceanSITES, **Fig. 3**), moored profilers, bottom moorings, bottom landers, and cabled arrays (e.g., HOTS, OOI (Ocean Observatories Initiative), MBARI's MARS (Monterey Accelerated Research System), and Ocean Networks Canada's VENUS (Victoria Experimental Network Under the Sea) and NEPTUNE (NorthEast Pacific Time –series Underwater Network System) arrays). Sensors that should commonly be deployed on these systems include temperature, salinity, density, oxygen, pH, $CO_2$, nitrate, Chl-a fluorescence, radiation, current (ADCP), and turbidity. Stationary systems can provide continuous time-series data, thus filling temporal gaps between ship surveys. Stationary platforms also allow simultaneous observations of multiple variables and processes, and have the ability to support sensors that have high power requirements. Ship operations could be paired with stationary-platform observations for calibration and ground-truthing of sensors.

There are other non-traditional fixed platforms that could be leveraged for opportunistic scientific monitoring, such as: (1) drilling ships and offshore wind and oil platforms (e.g., BP SERPENT partnership in the Gulf of Mexico[25]), and (2) deep water piped from >100m for cosmetics[26] and aquaria[27,28].

Many moorings and other stationary installations have only a single purpose or application. With the basic infrastructure already in place, these installments could be leveraged by

25 http://www.serpentproject.com/aboutus.php

26 https://pdobiotech.com/applications/cosmetics-and-skin/

27 Nakasone, T. and S. Akeda. 1999. The application of deep sea water in Japan. Proc 28th UJNR Aquac Panel Symp, UJNR Technical Report No. 28.

28 Avery, W.H. and C. Wu. 1994. Renewable Energy from the Ocean: A Guide to OTEC. Oxford University Press. 466 pp.

incorporating:

1. High-priority multidisciplinary sensors at relatively low cost. Some examples are wideband acoustics, bioluminescence detectors, flow cytometers, environmental sample processors, and optical sedimentation recorders.
2. Deep-sensors – although mooring lines provide wire access to the seafloor, most of the sensors are currently located near the surface.

Resource investment from multiple groups is needed to advance the multidisciplinary capabilities of LTONs. Two potential models to implement these recommendations **(Box 3)**:

1. Augment a distributed network - add priority capabilities to existing mooring networks.
2. Pool resources and deploy one or two novel observatories (moorings, lander, glider, etc.) in a priority geographic region (**pp. 7-8**).

**Box 3. Protocol for pilot demonstration**

1. Choose a sensor or multiple sensors (See **Table 1**) for the demonstration project, based on community-derived objectives and feasibility of mooring deployments.
2. Pick a subset of sites to conduct the demonstration where data are likely to have high value based on community input and feasibility (see list 'Geographical priorities for water column exploration' on **pp. 7-8**).
3. Invite operators of existing moorings to collaborate on a white paper that outlines the goals of the pilot project and justifies the need for long-term data with respect to understanding the poorly explored zones and regions of the ocean.
4. Submit a collaborative proposal for funding from agencies and private donors to fund the demonstration.

### ROV-based Observations and Sampling

Remotely operated vehicles (ROVs) are essential platforms for observing in situ behaviors, identifying and collecting delicate gelatinous animals, documenting fine-scale distributions of many pelagic fauna, and making simultaneous measurements of physical and chemical data.

Three different scenarios for which ROV-based work were considered:

**Scenario 1:** Collecting opportunistic midwater data during a non-dedicated dive (e.g., during ROV descent to and ascent from the seafloor)

**Scenario 2:** Re-configuring a benthic vehicle to conduct dedicated midwater work

**Scenario 3:** Operating a vehicle designed and optimized for midwater operations

Detailed recommendations for each of these scenarios are outlined in **Appendix 4**.

### Innovative and Autonomous Systems

There are two broad categories of non-traditional systems for exploring the water column: (1) biological and (2) mechanical.

### Biological

**Animals as sensor platforms:** Bio-logging is the use of sensor-tagged animals to explore the ocean (e.g., Animal Telemetry Network[29]). Depending on the species, environmental sampling by animals can occur at local to basin scales. Northern elephant seals have been used to collect both CTD data and imagery in excess of 1000 m water depth across 6400 km[30]. Innovations such as Crittercam[31] provide powerful platforms to study targeted animal behavior over relatively short timeframes. A trade-off exists in the resolution of sampling using biologging. CTD data collection is essentially continuous, while the high power and data storage needs required for imaging limits the quantity of photographic and video observations.

**Animals as sensors:** Animals themselves can be excellent integrators of their environment. Gut contents provide information on distributions and availability of prey items, and otolith chemistry can be used to track different environmental characteristics over the lifetime of a fish. Such integrated approaches to detecting long-term trends in the ecology of the midwater community could enrich the understanding of feeding ecology and anthropogenic contamination in the midwater realm[32]. Innovative exploration using biological platforms could leverage NOAA fisheries observer programs, where stomachs and otoliths are readily collected.

## Mechanical

Many of the priority data types, such as light, dissolved oxygen, CTD measurements, pH, and carbonate chemistry parameters (see **Table 1**), can be measured using mechanical sensors. There are two platform types for mechanical sensors - stationary and mobile - which address different measurement scales. Stationary monitoring systems provide rich temporal datasets, but with limited spatial coverage. Examples include Baited Remote Underwater Vehicles (BRUVs) and passive samplers/time lapse arrays. Mobile monitoring platforms, such as AUVs and gliders, allow collection of rich

### Box 4. Best practices for leveraging existing programs

**Leadership and collaboration**

In order to augment existing research programs, a champion individual or institution is required to manage calibration and data storage, serving, and analysis for that data type in order to ensure that high quality data are collected, shared, and processed for characterization products (e.g., UHDAS for ADCP data, Multibeam Advisory Committee for UNOLS' multibeam data). Such champions ensure that datasets are directly comparable. Annual calibrations for each data type should be conducted and well-documented such that resulting data are of quality that can be used in scientific reporting.

**Operational Planning**

To maximize the benefit of a leveraged program, a strong operational protocol must be in place. This would include communication/announcement of cruise locations across all platforms (e.g., NOAA Ship *Okeanos Explorer* use of SeaSketch to share general cruise tracks for the field season), agreements between lead organizers of different data collection types, and details on how associated costs (e.g., money, time, staffing, shipping and handling) for ancillary data collection will be paid. In order not to burden an existing field program, a data management plan must be implemented that includes a chain of stewardship from data acquisition to data archival. The acquisition of ancillary data should be automated as much as possible to avoid overburdening onboard staff.

29 Block et al. 2016. Anim Biotelem. 4:6. doi: 10.1186/s40317-015-0092-1.
30 Saijo et al. 2017. DSR II. 140: 163-170. doi: 10.1016/j.dsr2.2016.11.007.
31 Marshall. 1998. Mar. Technol. Soc. J. 32(1):11-17.
32 Portner et al. 2017. DSR II. 125:40-51. doi: 10.1016/j.dsr.2017.04.013.

spatial datasets but are generally limited temporally to a maximum of months, and typically far less. Profiling floats and drifters, like *Driftcam*[33], the *Clio* biogeochemical AUV Sampler[34], and Bio-Argo have attributes of both mobile and stationary platforms. Promising frontiers for advancement in mobile platforms include capabilities for autonomous eDNA sampling and video transecting.

Some remaining challenges for widescale use of autonomous sensor platforms include limited battery power, biofouling of instruments, and data ground-truthing, calibration, and validation.

To reiterate what was stated in **Section IV**, comprehensive exploration of the water column requires a toolbox filled with a suite of tools. Innovative and autonomous sensors are key platforms for these tools. Efforts to explore the water column must utilize the diversity of systems to appropriately match measurements to the scale of observations required to answer the critical questions. For example, basin-scale exploration will require the use of long-range AUV platforms capable of extended deployments on the scale of weeks to months, while short-term event or process-based studies can exploit genomic gliders, smaller AUV platforms, and static floating camera arrays. The development of smaller autonomous platforms such as *Mesobot*[35], Driftcam, *Clio*, and low-cost ASVs or AUVs allow the use of small craft to access the nearshore water column from coasts. The use of small craft greatly reduces logistical costs and allows for testing and deployment sensing platforms and techniques without requiring extensive shiptime. Resources should be invested in this full range of platforms.

The group finally discussed how best to leverage existing programs, platforms, and technologies. Recommendations are summarized in **Box 4**.

33 ftp://128.171.151.230/bhowe/outgoing/IEEEOES_2013/papers/130501-017.pdf
34 http://www.whoi.edu/page.do?pid=136317
35 http://www.whoi.edu/main/mesobot

# VI. The Future of Water Column Exploration

The ideal exploration program will be interdisciplinary and developed with ongoing input from the broader scientific community to build on existing expertise and infrastructure. Spatial and temporal baselines are necessary to understand the pelagic environment and assess anthropogenic impacts, while collections and manipulative investigations are required for many organismal studies.

At the conclusion of the workshop, a framework for ongoing development of a water column exploration program was proposed comprised of six components:

1. **Identify and refine seminal questions and key regions**
This will be accomplished through ongoing dialogue among the water column science community. A "Water Column Explorers" listserv was established following the workshop as a means to facilitate communication within the community. The questions and priority regions outlined earlier in this report (Section III) are a starting point for this, and should be regularly revisited and refined based on current research priorities. Additional input will be obtained through follow-up workshops, working groups, the annual Ocean Exploration Forums, and conference participation.

2. **Collect reconnaissance data (Table 1, Tier 1 data) from long-term research monitoring tools at each region**
Resources should be used to leverage existing moorings, observatories, Argo floats, animal-based sensors, and research expeditions to collect essential data. The reconnaissance component of the program will be expanded to a network of heavily-instrumented stationary installations that provide fine-scale temporal observations sufficient to detect event phenomena in key regions. Spatial reconnaissance will be extended geographically by the inclusion of autonomous vehicle surveys beyond the bounds of a given regime. Long-range autonomous systems will build these out further to improve understanding of global trends, patterns, and baselines. Animal-based sensing will be improved to include capabilities for low-light imaging, improved memory, and tag miniaturization to track animals that we have not yet been able to observe.

3. **Develop technologies guided by the seminal questions**
The ambitious goal of building a coordinated water column exploration program requires conceptual innovations and technology developments to address the scientific questions in the challenging midwater environment. New sensors and improvements on existing sensors (e.g., endurance, calibration, miniaturization) are essential. Some examples of anticipated sensors will measure micro-nutrients, use olfaction, and image plankton within large volumes of water. Improvements are expected in broadband acoustic technology, aerial deployable sensors, flow cytometers, and composite camera systems. Operations will feature coordinated heterogeneous fleets of autonomous platforms such as AUVs, gliders, floats, profilers, UAVs (aerial drones), and ASVs (autonomous surface vehicles) with sensors. These instruments will communicate with each other and use Artificial Intelligence to enable adaptive missions to identify and survey features such as fronts, plumes, and thin layers. Improved endurance and battery storage will greatly increase the spatial and temporal extent of records. Energy-scavenging combined with docking/recharge capabilities will create new mission types, such as transiting to remote sites and loitering at

sea awaiting rare events, and could employ high-power-using sensors currently unavailable on autonomous systems. Present day AUVs can sample water and obtain pumped-filter samples, but cannot sample specific targets. Future autonomous systems will be able to identify animals and other midwater targets (e.g., aggregates, plastics, bubbles) and sample them. Finally, techniques for automated sample preservation, storage, and/or analyses will become routine, such as for eDNA, nutrients, -omics, and acoustics. With appropriate resource input, a revolution in autonomous systems and techniques is feasible in the next decade.

**4. Conduct dedicated, midwater cruises to perform intensive sampling (Table 1, Tier 2 data)**
Ship-based sampling remains essential because sampling with nets and ROVs is the only way to acquire organisms crucial to address most of the ecosystem questions posed in Section III. Collections provide material to make morphological and genetic identifications, tissue samples for fatty acid and stable isotope analyses, stomachs for diet analyses, and live organisms for physiological and other experiments. Further developments of in situ deep midwater experimental capabilities are anticipated.

**5. Strategize sample processing, data management, and analyses**
Oceanographic instrumentation and protocols should be standardized to facilitate integration of different data sources, and ensure that data and metadata meet international standards (e.g., U.S. Integrated Ocean Observing System (IOOS)[36], Ocean Biogeographic Information System (OBIS)[37]) in order to facilitate utilization of legacy data to develop broad syntheses. Advancements of in situ and laboratory processing techniques, biological modeling practices, and computing power for statistical analyses and modeling will all be essential to addressing the seminal exploration questions. An open-access "critter library" database should be developed to serve as an inventory for all organisms that have DNA barcodes, distribution information, in situ imagery, and/or physical tissue samples available.

**6. Event Response**
The dynamic nature of the water column inherently presents significant challenges for developing capabilities to establish its baseline physical, chemical, and biological characteristics. One such challenge is finding ways to not only gain a meaningful understanding of the "normal state" of the water column in any given locality, but to be able to recognize and study episodic anomalies, i.e., unusual natural or anthropogenic events. This will sometimes require mobilizing rapid responses in order to characterize an environment in its altered state. Effective event response, whether for long-duration or short-duration events, will necessitate establishing a response capability that, because of unpredictable logistical challenges, will require the combined efforts of more than a single program or agency. An effective example of such a collaboration was the joint effort by the NOAA Vents program and National Science Foundation/Division of Ocean Sciences to respond to the onset of a submarine volcanic eruption in the NE Pacific by rapidly mobilizing seagoing assets and personnel. The outcome of the effort was highly successful in terms of discoveries concerning, among other things, the immediate water column impacts of such eruptions. New technologies may need to be developed with event response capabilities in mind (e.g., develop a system of remotely triggered autonomous samplers to enable immediate sampling in response to events). Prioritizing marine protected areas or locations at particular risk from anomalous events should be considered in designing event

36 https://ioos.noaa.gov
37 http://www.iobis.org

response capabilities and identifying response partners.

As the lead on U.S. national exploration efforts, NOAA OER could spearhead the effort to support collaborations between stakeholders to achieve these six goals.

With regard to Question #5 “How do we get people to care?” (**Appendix 3, p. 28**), NOAA OER, OET, and SOI have made significant inroads in reaching the public by livestreaming ROV exploration and to youth through the educational programming[38]. The citizen science Facebook group Underwater Screenshot Sharing is a good example of an organic community that has formed around the shared interest of ocean exploration. Other opportunities for engagement include giving short talks at schools, libraries, and TEDx events. A compelling method to bring the excitement of exploring the deep water column is through immersive experiences, such as using 3D video or virtual reality technology to visualize the mesopelagic environment, organisms, and bioluminescence. This important topic must be revisited in future discussions in order to develop further tools to reach the public to muster broad support for water column exploration.

Achieving the vision of a comprehensive, multi-institutional, and interdisciplinary water column exploration program that reveals the unknown components of this critical environment requires investment now in novel technologies, strong interagency and international coordination, and maintenance and improvement of the exploration fleet. Existing technologies such as telepresence and imaging capabilities provide inspiration for mustering political will and public support. The water column exploration community must continue to communicate the wonder and importance of this environment.

38 http://oceanexplorer.noaa.gov/edu/welcome.html

## Concluding Thoughts (by Bruce Robison)

This workshop report reflects the growing recognition within the research community that exploring the oceanic water column is the next pivotal step toward understanding Earth's largest ecosystems. Primary production patterns at the surface and processes at the deep seafloor have been the targets of focused research for decades; and now the vast ecological regime that separates and unites these two biomes – the water column – represents the biggest gap in our knowledge. This workshop built on momentum generated earlier in the week by a NOAA/OER-orchestrated session (at the ASLO 2017 Aquatic Sciences Meeting) on *Characterizing Exploration in the Water Column*[39]. With a broad cross-section of the research community in attendance, this workshop dealt with the challenges and opportunities of advancing water column research and developed a roadmap for future action.

One of the principal challenges to be faced is that while there is widespread interest in water column research, the practitioners of water column science have been working independently, with insufficient integration or coordination. The workshop provided a catalyst for creating a forum and a voice for the midwater research community. After considering the multi-disciplinary scope of water column exploration and then reviewing previous efforts to galvanize community support for midwater research in the shadow of long-established near-surface and benthic programs, the workshop addressed the principal issues. First is the recognition that knowledge of the ocean's largest habitat is still so limited that exploration remains a necessary first step. This was followed by discussions of the critical questions in water column exploration. Basically, these questions are centered on the composition, structure, and dynamics of midwater communities, as well as their patterns of variability in response to natural and anthropogenic influences.

Once the essential questions had been defined the discourse shifted to a determination of what kinds of data are needed and how they should be managed. All agreed that the goal for any region should be to determine a baseline characterization, against which changes can be contrasted and predictions generated. Data options run the gamut from optical and acoustic imaging to physical sampling for molecular and whole-animal investigations. Data quality, sharing, and compatibility will be significant issues but the prospect of automated data collection and analysis is an attainable goal with technologies that are already available.

Subsequent topics of discussion included where best to explore and the regional characteristics that would lead to such determinations. Consideration was also given to how aspects of water column research could be introduced into field programs principally dedicated to other types of investigations. The latter encompassed the incorporation of specific sensors into long-term observation networks—either ship-based, as part of cabled arrays, or attached to moorings and profiling floats. The promise and challenges of adopting animals as sensor platforms, as well as using next-generation AUVs and gliders were also reviewed as promising alternatives.

39 Netburn, A.N. and K. Cantwell. Limnol Oc Bull. 26:84. doi: 10.1002/lob.10186.

Clearly, the best option for exploring the oceanic water column is a dedicated, coordinated effort. With this in mind the workshop generated outlines for both near-term and long-term programs. To achieve the goals established by the workshop it will be necessary to make the case for water column exploration. One challenge will be to elevate the recognition of the importance of water column science within the community of programs and agencies that have the means to provide the required funding. While the workshop attendees are well aware of the global significance of the midwaters, much of the rest of the oceanographic community is not. Those who study the water column know that in the few places that have been explored, it is packed with life from surface to seafloor. Many technologies to make the necessary advances already exist. Now the key is to put them into the hands of the water column exploration and research communities with the support of long-term funding commitments.

# Acknowledgements

Thank you to all of the workshop participants for providing expert advice and for the engaging discussions that occurred at the Surface to Seafloor workshop. I'd also like to thank everyone who presented at the workshop—Alan Leonardi, Uwe Send, Chris Hayes, Anni Djurhuus, Tracey Sutton, Marsh Youngbluth, Steve Haddock, Kasey Cantwell, Carlie Wiener, and Bruce Robison. Thank you to Doug Harper for his generous assistance facilitating the meeting. All workshop participants contributed directly to this report by providing summary documents of the breakout group discussions, and these contributions are greatly appreciated. Special thanks is also due to Stephen Hammond and George Matsumoto for insightful comments on later drafts of this document. Thank you to Matt King (NOAA OER) for formatting the final version of the report. Finally, I'd like to thank NOAA OER and CIOERT/FAU for sponsoring the workshop, and the University of Hawaii for providing in-kind space to host the workshop.

# Appendix 1. Agenda

### From Surface to Seafloor: Exploration of the Water Column

**Dates:** 4-5 March
**Location:** Honolulu, HI
**Venue:** UH Manoa Campus Center, room 308
**Facilitators:** Amanda N. Netburn, Doug Harper
**Contact Info:** Amanda Netburn Cell (650)-387-9337

The workshop From Surface to Seafloor: Exploration of the Water Column is a two-day workshop to convene expert scientists, technologists, and program leaders to discuss the future of ocean exploration in the water column environment. The goal of this workshop is to propel the exploration community beyond the current spatial, temporal, and technological limits of water column science. Products that will come out of this workshop are a workshop report including a prioritized list of exploration objectives, protocol recommendations, and future opportunities for water column exploration. The workshop report will synthesize the key questions and recommendations of the expert group, and be essential to informing national ocean exploration efforts in terms of current and long-term goals and priorities. It will help guide future funding opportunity announcements and be informative for designing pilot projects. This effort will help initiate a new era of collaborative exploration activities in the water column.

### Day 1: March 4, 2017

**Morning**

| | |
|---|---|
| 8:00-8:30 | Registration and Breakfast |
| 8:30-8:45 | Welcome (Amanda Netburn) |
| 8:45-9:00 | Introduction (Alan Leonardi) |
| 9:00-10:00 | Overview science talks- What are most impactful discoveries to date and what are cutting edge frontiers moving into future? |
| 9:00-9:15 | Multi-disciplinary sensors and mooring observations (Uwe Send) |
| 9:15-9:30 | Chemistry (Chris Hayes) |
| 9:30-9:45 | Biology – Micro (Anni Djurhuus) |
| 9:45-10:00 | Biology – Plankton/Nekton (Tracey Sutton) |
| 10:00-10:30 | Break |
| 10:30-11:00 | Recent opportunities for community input |
| 10:30-10:45 | DESCEND 2 workshop (Marsh Youngbluth) |
| 10:45-11:00 | National Academies Keck Futures Initiative (NAKFI) Discovering the Deep Blue Sea (Steve Haddock) |
| 11:00-12:30 | Breakout Session I |

**Afternoon**

| | |
|---|---|
| 12:30 - 13:30 | Lunch |
| 13:30 - 14:30 | Session I report out and discussion |
| 14:30 - 16:30 | Breakout Session II (Coffee and snacks available) |

| | |
|---|---|
| 16:30 - 17:30 | Session II report out and discussion |
| 18:00 | Pau Hana/Dinner (Tiki's Grill and Bar) |

## Day 2: March 5, 2017

**Morning**

| | |
|---|---|
| 8:00-8:30 | Breakfast |
| 8:30-8:45 | Welcome (Doug/Amanda) |
| 8:45-9:30 | Overview talks on opportunities |
| 8:45-9:00 | OER/OET overview (Kasey Cantwell) |
| 9:00-9:15 | SOI overview (Carlie Wiener) |
| 9:15-9:30 | MBARI overview (Bruce Robison) |
| 9:30-11:00 | Breakout Session III (Coffee and snacks available) |
| 11:00-12:00 | Report out and discussion |
| 12:00-13:30 | Lunch/Group Photo/Solicit feedback on next steps |

**Afternoon**

| | |
|---|---|
| 13:30-14:30 | Next Steps -review of feedback & large group discussion |
| 14:30-14:45 | Overview of writing tasks (Amanda) |
| 14:45-15:15 | Break/Sign up for writing tasks |
| 15:00-16:30 | Group writing |
| 16:30-17:00 | Wrap up |

## Breakout Session Guidelines:

### Session I: What?

In the first breakout session, participants will outline exploration and research data requirements in the context of the water column. Groups will consider one of two exploration themes:

1. **Baseline characterization (2 groups)**

Primary:

What is a "baseline characterization" in the context of the water column?
If you could only go to a spot in the ocean once, what is the most critical information that you would need to characterize the physics, chemistry, and biology of the water column there? Please do not consider the data collection platform or current technological limitations. Be specific, and create a **prioritized list** of data collection objectives.

Secondary (if you have extra time, discuss the following):

What geographical locations should be prioritized for future exploration of the water column? (i.e., areas where we lack robust data or have particularly interesting features to explore)

2. **Research needs (2 groups)**

   Primary:

   What are the main scientific questions/gaps relating to the water column?
   What are the minimum data needs to address these questions?
   Please do not consider the data collection platform or current technological limitations.
   Be specific, and create a **prioritized list** of both the research questions and data needs.

   Secondary (if you have extra time, discuss the following):

   What are the current limitations to accessing or collecting those data? How could these be addressed?
   - Cost Limitations – How can we come up with the most cost-effective approaches to collecting water column data?
   - Technology limitations- How can existing technologies be used or improved upon to obtain the data we need? What new technologies should be developed?

**Session II: How?**
Opportunistic data collection – How can existing opportunities and assets be leveraged to provide the data needed to address the exploration and research priorities that were developed in breakout session I? (For example, on a seafloor ROV cruise, could a couple of hours be dedicated to water column transects at set depths/features to expand the geographic scope of midwater ROV operations and compare between sites?). Each group should outline **specific protocols** that could be used to leverage the opportunities they are assigned. More detailed guidance will be provided to each breakout group at the workshop.

1. ROV (1 group)
2. Geological and hydrographic cruises (1 group)
3. Long-term observing networks (1 group)
4. Innovative and autonomous systems (1 group)

**Session III: When?**
Participants are asked to design a dedicated water column exploration strategy, considering the priorities that were developed in session I. The first two groups will design coordinated water column exploration programs that could be implemented in the next 1-5 years, utilizing currently available technologies. The second two groups should think well into the future and beyond current financial and technical limitations, incorporate “out-of-the-box” thinking, and be highly ambitious.

1. Near-term (1-5 years, 2 groups)
2. Long-term (10+ years, 2 groups)

# Appendix 2. List of Participants[40]

| Name | Institution |
|---|---|
| Dag L. Asknes | University of Bergen |
| Ruhul Amin | NOAA Pacific Islands Fisheries Science Center (PIFSC) |
| Edward T. Baker | University of Washington and NOAA/Pacific Marine Environmental Laboratory (PMEL) |
| Chris Beaverson | NOAA Ocean Exploration & Research (OER) |
| Barbara Block | Stanford University, Hopkins Marine Station |
| John "Chip" Breier | University of Texas Rio Grande Valley |
| Kasey Cantwell | NOAA Ocean Exploration & Research (OER) |
| Collin Closek | Stanford University, Center for Ocean Solutions |
| Anni Djurhuus | University of South Florida |
| Jeffrey Drazen | University of Hawai'i, Mānoa |
| Michael Ford | NOAA National Marine Fisheries Service (NMFS) Office of Science and Technology |
| Giacomo Giorli | University of Hawai'i, Mānoa |
| Alistair Grinham | The University of Queensland |
| Steven Haddock | Monterey Bay Aquarium Research Institute (MBARI) |

40 Biographies can be found here: http://oceanexplorer.noaa.gov/fsts/participants.html

| Name | Institution |
|---|---|
| Doug Harper | NOAA/National Ocean Service (NOS) Office for Coastal Management |
| Christopher Hayes | University of Southern Mississippi |
| Brad Henning | National Geographic |
| Rachel Holser | University of California, Santa Cruz |
| Russ Hopcroft | University of Alaska |
| Cornelia Jaspers | Technical University of Denmark |
| Heather Judkins | University of South Florida St. Petersburg |
| Chris Kelley | University of Hawaiʻi, Mānoa |
| Astrid Leitner | University of Hawaiʻi, Mānoa |
| Alan Leonardi | NOAA Ocean Exploration & Research (OER) |
| Dhugal Lindsay | Japan Agency for Marine-Earth Science and Technology Center (JAMSTEC) |
| Meme Lobecker | NOAA Ocean Exploration & Research (OER) |
| George I. Matsumoto | Monterey Bay Aquarium Research Institute (MBARI) |
| Rosanna Milligan | NOVA Southeastern University |
| Enrique Montes | University of South Florida |
| Aditya Nayak | NOAA Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) and Harbor Branch Oceanographic Institute (HBOI) |
| Amanda N. Netburn | CIOERT/Florida Atlantic University & NOAA OER |
| Karen Osborn | Smithsonian National Museum of Natural History |
| Frank Parrish | NOAA NMFS Pacific Island Fisheries Science Center |
| Brennan Phillips | Harvard University |
| Elan Portner | Stanford University, Hopkins Marine Station |
| Kim Reisenbichler | Monterey Bay Aquarium Research Institute (MBARI) |
| Joseph Resing | Joint Institute for the Study of the Atmosphere and Ocean (JISAO)-University of Washington and NOAA PMEL |
| Bruce Robison | Monterey Bay Aquarium Research Institute (MBARI) |
| Michael Seki | NOAA NMFS Pacific Island Fisheries Science Center |
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# Appendix 3. Scientific Questions and Knowledge Gaps Relating to the Water Column

## 1. What lives in the water column?

### a) Biodiversity

- Who's there and where in the water column (depth, geography) do they reside? There remain many undescribed species and unexpected lifestyles in the pelagic habitat.
- What is the relative importance of different components of the pelagic environment with respect to size (e.g., microbes vs. macrofauna) and faunal groups (jellies vs. hard bodied)?
- What is the biodiversity and distribution of gelatinous fauna **(See Box 1. The Unknown Gelatinous Fauna on p. 7)** We have limited information on spatial and temporal variations in fishes and crustaceans but much less for other taxa.
- What is the diversity of marine microbes?

### b) Evolutionary Processes

- What are key adaptations for survival in pelagic habitats and how did they evolve?
- What are the evolutionary rates in the deep pelagic? How do we measure these?

### c) Deep scattering layer (DSL)

- What is the DSL made of?
- How do the DSL animals do what they do (e.g., change depth)? What are their cues?
- What are the ramifications of the moving layer for chemical and physical oceanographic processes and vice versa?

### d) Behavior

- What are the trophic interactions – who eats whom and when?
- What are behaviors related to reproduction? How do conspecifics find each other for reproduction in such a vast habitat?
- What are undisturbed behaviors? We can almost never see these animals acting normally in situ. What are some less intrusive methods we could use to make observations?

### e) Biogeography

- Why are organisms distributed heterogeneously both vertically and geographically?
- What factors control abundance, biomass, and community composition?

- How do the animals sense and move around within their environment?
- How do we evaluate what is representative and what is a hotspot?
- How does global topography influence water column biology and physics?
- When, where (in both the horizontal and vertical), and why do midwater fauna aggregate?

**f) Temporal Variability**

- How do we disentangle multiple sources of temporal variation in midwater communities?
- How are ecosystem structure and function affected by natural and anthropogenic changes?
- What are hot spots? What's representative?

## 2. How is the water column structured? Do the different zones need to be redefined?

**a) Physical**

- What is the structure of deep water circulation at different scales?

**b) Chemical**

- How do chemical transformations in the water column impact carbon and other biogeochemical cycles?

**c) Energy**

- What is the energy flux (active and passive) between different depths of the water column?
- What are the roles of pelagic organisms in the long-term maintenance and short-term variability of nutrient cycles in the ocean?
- What is the role of midwater processes in the biological carbon pump and vertical coupling of food webs?

**d) Connectivity**

- How are the vertical zones of the ocean linked to each other?
- How are pelagic and benthic environments linked? What is the role of the bathymetry and geologic events (e.g. volcanic eruption) in determining structure in the water column?

## 3. What are the anthropogenic influences or natural variability?

**a) What are the physiological responses/tolerances to climate change?**

**b) How do nutrient inputs affect biogeochemistry in the water column?**

c) **How do toxins (e.g., metals and synthetic chemicals) accumulate in pelagic food webs? What is the effect on animals that people consume?**

d) **What mechanisms govern the distribution of plastics in the upper ocean and the deep sea? How does marine litter impact biota?**

e) **How do we detect and observe episodic short-timescale events in the deep ocean?**

## 4. Do we know what we don't know?

a) **Bathypelagic**

- What is the abundance, biomass, and community composition of bathypelagic organisms? How is the bathypelagic connected to the mesopelagic and seafloor?

b) **Hadalpelagic (See Box 2. Hadalpelagic on p. 8)**

- Is the hadalpelagic different from the bathypelagic as in benthic environments, or is this an inaccurate ecological distinction?
- Is there a biomass increase near the seabed or down-trench as hypothesized?

c) **How do we challenge the current assumptions about the ocean?**

d) **We have only recently learned about the microbial loop, the abundance of gelatinous animals, and the massive biomass of fishes in the water column. What have we not discovered yet?**

## 5. How do we get people to care?

a) **How do we communicate the importance of the water column to the public and regulators?**

# Appendix 4. ROV-based Observations and Sampling

## Scenario 1: The opportunistic midwater dive

In Scenario 1, the ROV dive is a dive dedicated primarily to seafloor operations. The goal is to collect ancillary midwater data without interfering with benthic operations. The strategy is to collect high-quality images of midwater organisms and correlate pelagic species occurrences with ambient water column parameters.

### Recommendations/Requirements

**Camera:**

- Conduct white balance early in the dive
- Image an object of known scale for size calibration at full zoom out and zoom in
- Adjust camera and lights to optimize for water column imaging during midwater portion of dive
  - Light source as far from camera as possible
  - Lights at full intensity with camera iris as small as possible to increase depth of field
  - Camera heading such that the marine snow particles approach the camera head-on so for any organisms that are imaged at least one frame will be in focus.
- Record high-definition video throughout the descent at 60 frames per second if possible. Maximum descent speed <15m $min^{-1}$
- Always record video during descent when tether interference is minimal; Record during the ascent leg as a second priority

**Metadata:**

- Document depth, location, and UTC time code
- Log CTD data in a manner that can be cross-referenced to the video
- Log oxygen data as available

**Operational recommendations:**

- Include some forward motion on the vehicle while descending obliquely (*High priority)
- Descend at a rate of ~ 15 m/min as dive time permits (based on bottom depth) to reduce video smearing of organisms and particles moving rapidly across screen
- Incorporate a “time budget” for water column observations that can be pre-determined based on depth and dive plan, with some time allocated to allow longer observations en route

- Focus camera toward the far end of its range
- Stop opportunistically on animals of special interest
- Provide audio record of size estimate for organisms of interest, and depth, to confirm synchronization of video and physical sensors

## Scenario 2: Dedicated midwater work on a benthic-focused vehicle

In the second scenario, midwater researchers collaborate with a benthic team for dedicated time to gather high-quality water-column data.

### Recommendations/Requirements

**Instrumentation:**

- Include CTD, oxygen, transmissometer, and fluorescence sensors in the vehicle's core capabilities.
- Incorporate closely-set lasers for sizing (Note: this can be achieved with a beam-splitter without the requirements of additional cabling, control, or housing)
- Ideally, collection capabilities would be mounted to the ROV, e.g., multi-chamber suction device and/or ram-operated "detritus" samplers
- Measure distance traveled relative to the water with ADCP (Acoustic Doppler Current Profiler) or ACM (Acoustic Current Meter) for quantitative transects; also need to define the light field
- Use swing-arms to provide side-lighting

**Operations:**

- The vehicle control software could be modified to include a "Midwater Mode", in which the thrusters will not push water into the field of view at the front of the vehicle
- Utilize a fine-control thruster mode. Navigation in the midwater is easier when the power of the thrusters is reduced to make the controls less reactive to small piloting adjustments

## Scenario 3: ROV operations dedicated to water column surveys

This scenario includes a recommendation for scientist support, with a scientist participating in the dive alongside the pilot(s). For midwater work, the use of a single body vehicle (this type of vehicle is also preferred by many benthic scientists) should be equipped as follows:

**Vehicle:**

- A Variable Ballast (VB) system is essential for operating in the water column. All facets of ROV operation (collecting, transecting) are simpler with a VB system

- Fine-control as well as Midwater Mode (see above)
- The ‘front porch’ often used on benthic dives for collections (e.g., core-samples) interferes with mesopelagic collections and should be removed or retracted
- Samplers: both suction samplers and ram-operated detritus samplers (for fragile animals).
- A device to measure the size range of particulate matter
- ADCP or ACM to determine the distance traveled and vehicle speed

**Camera:**

- Pan/tilt capabilities for both lights and camera
- Focus, zoom, and iris control should be automatic and with manual override.
- White/Red/Blue light capabilities with adjustable intensity
- 4K camera recommended because of current ability to store and view video (with an eye to 8K in future). Video should be recorded with minimal compression and a confidence monitor employed to be sure that video is being recorded.
- Camera **must be calibrated for Field of View** (FOV) in order to calculate volume for observations made. Trying to determine animal densities based on time at depth is inaccurate, difficult, and cannot be compared to other data, e.g., net tows.

**Forward-looking capabilities that would be of use for special projects:**

- Video Plankton Recorder (VPR) or Underwater Vision Profiler
- Stereo camera (will allow size/biomass measurements)
- A secondary 4k camera optimized for mesozooplankton
- Slab/structured lighting
- Means to take tissue sample
- In situ filtering system for water samples
- In situ fixation
- Deep Particle Image Velocimetry (PIV)

**Scenarios 2 & 3** require the ability to make slow, oblique transects through the water column. These horizontal transects will be useful when several visits are made to the same location. At a minimum, 4 fixed levels should be surveyed. These depths should be determined based on the site’s hydrographic features. An example scenario is: (1) epipelagic (100-200 m), (2) mesopelagic (300-600 m), (3) benthic boundary layer (depth tbd based on seafloor depth), and deep scattering layer (depth tbd based on bioacoustics detection). Training is required for the pilots with respect to maneuvering the vehicles in the water column and near the seafloor (i.e., maintaining buoyancy, limiting thruster usage, maneuvering into prevailing currents, and target recognition).

### Dive Protocol

For all 3 of the scenarios, recommendations are to:

- Use a controlled, smooth, descent with forward motion during transits and oblique transects.
- Make sure camera is wide (not zoomed).
- Lights may be turned on or off (the latter to observe bioluminescence).
- Allow for more relaxed station keeping, i.e., the ability to stop and record/observe interesting animals in the water column for at least short periods of time. Behavioral observations can aid in making identifications.
- Pilots and scientists should work side-by-side to facilitate communication during operations.

### Onboard Ship

- Environmental temperature-light control lab for observing and experimenting with animals after collection

### Data Management

ROV video and sample collection data need to be carefully managed following the dive. We recommend the following:

- Use VARS (MBARI's Video Annotation and Reference System), SeaScribe/SeaTube (Ocean Networks Canada) or another means to annotate video that synchronizes the image with all available ancillary data (biological observations, navigation, CTD, oxygen, etc.)
- Create the ability to take a frame grab or mark data in real-time so they can be re-visited with identification of person taking frame grab
- Embed timecode (LTC) in all videos with a Timecode Generator extracting time from satellite GPS
- Overlay option for video
- Dedicated personnel to annotate video
- Sample processing SOPs
- Specimen archiving SOPs
- Work toward automation for video/frame grab review and quantification