

OCEAN LIFE INSTITUTE



SPRING 2009 REPORT

Woods Hole Oceanographic Institution

Message from the OLI Director



Life in the ocean is threatened on many fronts, from global warming to pollution to over-fishing. Basic research sponsored by the Ocean Life Institute (OLI) during the past year has addressed several key issues related to ocean health and

biodiversity. This research included studies of how ocean physics and chemistry affect ocean life and was supported through OLI fellowships, postdoctoral and graduate student awards, and research grants.

New research grants funded by OLI during the past year covered a variety of topics, including studies of reef fish genetics and connectivity; chemical communication among bacteria; how marine animals respond genetically to environmental stress; and toxic algae that cause diuretic shellfish poisoning.

The Tropical Research Initiative supported five new grants, including research on hormone transfer between corals, geological analysis of ancient ocean circulation patterns, physics of equatorial waves, bacterial cycling of nutrients in the Pacific, and the importance of nitrogen-fixing bacteria in tropical estuaries. OLI has continued to support several studies at the Liquid Jungle Laboratory

in Panama. A new initiative on the oceanography of coral reefs is being developed to tie together several WHOI projects around the globe. A new study off Taiwan is being pursued to examine the impact of climate, ocean currents, and plankton on coral reef ecosystems and fisheries.

OLI continues to promote research in the area of ecosystem-based management and has worked to develop a new modeling-observing system in support of fisheries along the northeast US coast. A new multi-institutional proposal to NOAA was submitted, with WHOI as the lead, to establish the framework for such a system. The OLI has supported the use of a state-of-the-art computer model of ocean physics and biology to aid in the design of an ocean observing system in the Gulf of Maine-Georges Bank region.

Research projects of three OLI-supported scientists, and a MIT/WHOI Joint Program student are described in this report. Marco Coolen has developed new tools for analyzing DNA of ancient plankton communities, archived in layers of marine sediments, providing a glimpse into the past which was never before possible. Mak Saito is studying the proteins produced by microbes and their importance in ocean ecology and global nutrient cycling. Gareth Lawson is using new acoustic methods to study krill populations in the Gulf of Maine. Graduate student, Carter Esch, is studying the distributional patterns in prey of whales in the Arctic.

I would like to express my deepest appreciation for all who have supported the OLI.

—Cabell Davis



Ancient DNA in sediments

A New Window into Past Ecosystems and Environments

When plankton die, their remains sink and become buried in layers of bottom sediments. Marine and lake sediments thus compose archives of past plankton species and provide important clues about past environmental conditions, including the relative importance of natural versus human-induced climate change. Fossils of plankton (e.g., cysts, spores, silica- and calcareous skeletons) can be identified microscopically, but the vast majority of plankton are soft-bodied and leave no fossil remains. In the event that plankton fossils are not preserved, some plankton can be identified from their chemical traces (e.g., lipids and pigments), but most of these so-called lipid biomarkers are too general to provide species information.

I have found that these issues can be overcome by recovering ancient DNA from sediments. This discovery has led to the exciting new field of “sedimentary paleogenetics.” This field applies advanced tools to analyze preserved DNA “fingerprints” in sediment records. A major advantage of this approach is that individual species and even closely related strains of plankton can be separately identified and quantified, including those that did not leave the more traditional fossils and chemical traces in the sedimentary record. I have used these studies of ancient DNA to explore the effects of climate change on the plankton ecology of the Black Sea, Mediterranean Sea, and Antarctic lakes and fjords during the past 15,000–200,000 years.

My research program at WHOI is focused on the following overarching question: How have ocean, lake

and terrestrial ecosystems responded to past climate- and human-driven perturbations? Related questions include: (a) What species are contained in the sediments? (b) How well is the DNA of ancient plankton preserved in the geological record? (c) How are changes in ancient plankton species composition related to past climate change? (d) How do dormant microbes in ancient and extreme environments respond to climate change?



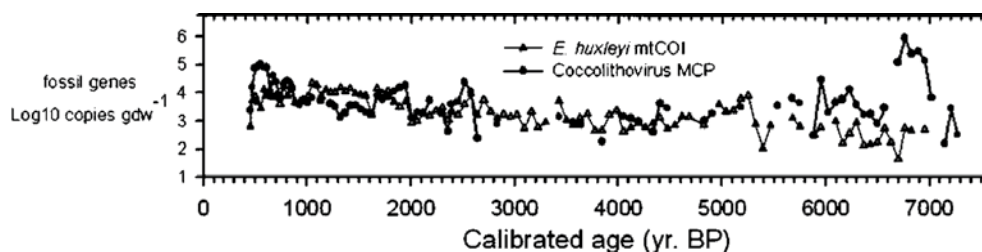
Marco Coolen

With OLI funding, I have explored the use of next-generation DNA sequencing to rapidly determine the entire suite of plankton species in the sediments. This exciting approach has revealed a far more extensive and precise view of plankton species dynamics in the Black Sea during the past 10,000 years. This sequencing has revealed previously overlooked species, which has provided information about the exact salinity of the Black Sea in the past and when Mediterranean waters first entered the Sea as a result of postglacial sea-level rise.

In addition, this DNA analysis method revealed the presence of the red tide algae, *Alexandrium*, roughly 7,000 years ago, and also the presence of the copepod *Centropages hamatus*, known to ingest *Alexandrium* cells. Furthermore, we identified DNA of soft-bodied species such as comb jellies, including *Mnemiopsis*, which invaded the Black Sea in 1980. This work lays the foundation for future paleo-DNA studies to determine whether red-tide species or jellyfish

are increasing world-wide as a result of human-induced or natural climate variability. More generally, I am using my OLI Fellowship to understand how ocean life has responded to climate change in the past in order to better understand how it will respond in the future.

—WHOI Chemist Marco Coolen



*Example of DNA data. Time history, over the last 7,500 years, of the phytoplankton (coccolithophore) species *Emiliania huxleyi*, and the virus that infects it, as determined from ancient DNA recovered from layers of Black Sea sediment.*

Proteomics and Iron Nutrition of the Oceans

New Technologies Help Unravel the Mysteries of Global Elemental Cycles

The study of the oceans is by definition an interdisciplinary science. In order to understand a marine ecosystem, scientists use the disciplines of biology, chemistry, physics and geology and so on. I remind myself of this as I frequent meetings in Boston sitting among cancer and pharmaceutical researchers from area hospitals and biotechnology companies, as we learn about the latest technological advances in the field of proteomics.

Proteomics is one of the latest of new “omics” fields of study (e.g., genomics, transcriptomics), which is simply and broadly defined as the study of all measurable proteins within an organism. Proteins are made of chains of amino acids and are one of the major building blocks of life.

They are the molecules tasked with innumerable functions, such as the enzymes involved in digestion (peptidases), composing our skin and hair (keratin), and the synthesis of pigment in our

eyes and skin (melanin), just to name a few. Because all life creates proteins based on codes contained in its DNA, techniques that measure proteins are the same whether the sample is for medical purposes or from a rare oceanic algal species. Moreover, the field of proteomics is relatively young; so, when researchers get together, there is often the sharing of vignettes of technical knowledge. The technology has matured in recent years to make this approach incredibly powerful.

My lab colleagues and I have been applying proteomic techniques to questions related to the marine carbon cycle. Understanding the oceans’ contribution to the global carbon cycle is critical in understanding the impact of greenhouse gases and climate change. In most regions of the oceans, the ability of algae to grow is limited by the availability of either nitrogen or iron as nutrients. Certain microbes have adapted to overcome limitation of nitrogen by acquiring or “fixing” nitrogen from the atmosphere. Not only are these microbes able to supply themselves, but they are one of the major suppliers of nitrogen to marine ecosystems. Yet, it turns out that this nitrogen fixation process requires an enormous amount of iron-containing enzymes. It has been a mystery how these microbes that fix nitrogen are able to do so in environments that are basically depleted in iron.

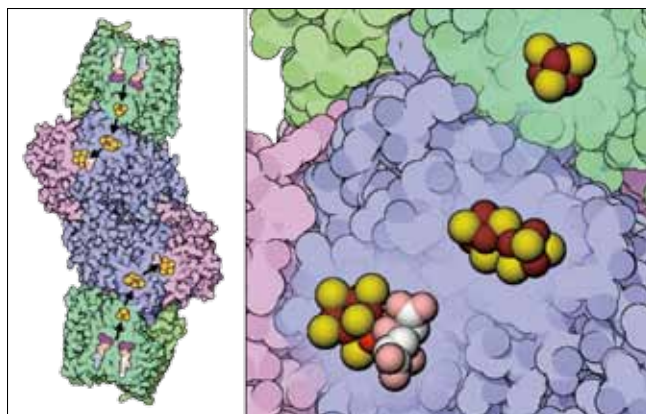
Using proteomic techniques, we have discovered that a particular marine microbe has a unique strategy for conserving the scarce iron for this iron intensive process. *Crocospaera watsonii* was discovered by Stanley Watson and John Waterbury here at WHOI in the 1970’s and is recognized as one of the major nitrogen fixers globally. This microbe uses a large amount of iron for both photosynthesis and nitrogen fixation. In order to conserve the iron, the *Crocospaera* synthesizes the nitrogen



Mak Saito in Antarctica doing field research on marine phytoplankton and their iron and cobalt requirements.

fixation proteins at night, then completely destroys them each day. Similarly, it takes some of its photosynthesis proteins and destroys them during the night, thus liberating its iron for use in nitrogen fixation. At first, we found this cycling of proteins very surprising; this process of remaking key proteins each day is extremely costly. But, when considering the incredible scarcity of iron in the oceans, this strategy clearly must be worth the energy expended. *Crocospaera* is effectively halving its iron demand by destroying iron containing proteins when not in use. There is even an appropriate marine metaphor for this: hotbunking, a term for when there are more sailors on a ship than bunks—the bunks are shared in shifts to save precious space. In our case, the iron is like the bunks, so valuable that they are always in use, and the sailors are like the proteins hotbunking in alternate shifts.

It's been quite exciting for us that one of our first applications of this new biomedical technology to oceanographic microbes has helped answer a major scientific question for



A three-dimensional image of the nitrogenase protein complex. (left) The molecule contains iron-sulfur and iron-molybdenum clusters (right) that are critical to the nitrogen fixing reaction of this molecule.

us. That's something else to remember the next time I find myself in a room full of cancer researchers learning the latest developments in proteomic mass spectrometry.

—WHOI Chemist Mak A. Saito

North Pacific Right Whale Acoustic Ecology

Many baleen whales produce loud, low frequency calls. But what do these calls mean? When and why do whales produce particular calls? It is important to understand this, since more and more monitoring of endangered whale populations is being accomplished by listening to their vocalizations. By leaving acoustic recorders out in the ocean for months at a time, we can monitor vocalizing whales without having to wait for good weather. This passive acoustic monitoring is less expensive and safer than visual surveys traditionally conducted by boat or plane. In order to most effectively interpret these large long-term acoustic datasets once they are retrieved, it is useful to know (1) what species produces any given call, (2) the context in which the call is usually produced and (3) how often any particular call is produced. This information can be gathered by making shorter-term visual ob-

servations of whales while recording calling behaviors and environmental conditions.

In July and August 2008, we participated in a cruise on the Bering Sea focused on studying the ecology of the North Pacific right whale (NPRW, one of the rarest baleen whales on the planet). Once we successfully located NPRWs (very exciting!!), we deployed an acoustic array to monitor call behavior and used an oceanographic sampling package to collect physical and biological oceanographic data. I am currently analyzing these data to determine patterns in NPRW call production, and how call production relates to the oceanographic context. Thanks to OLI support, this work will be a valuable part of my Ph.D. thesis and will hopefully contribute to the conservation of this highly endangered species.

—MIT/WHOI Joint Program, Biology Student H. Carter Esch



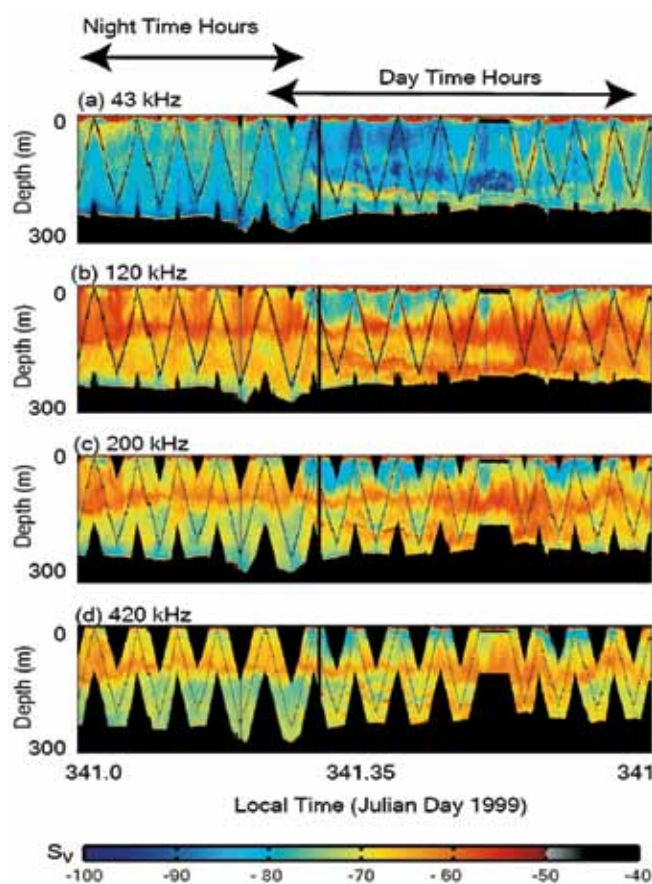
Zooplankton Ecology

Searching for Krill in the Deep Basins of the Gulf of Maine

The Gulf of Maine is one of the world's most productive fishing grounds. Instrumental to this productivity are the zooplankton, which form a key link in the food web between photosynthetic phytoplankton and higher predators, including fish and squid. Euphausiids, often referred to as 'krill,' are a common group of crustacean zooplankton in the marine ecosystems of the North Atlantic Ocean. In the Gulf of Maine, there is tantalizing evidence

based on limited observations that krill can be locally abundant and important members of the food web. In general, however, little is known about the seasonal distribution and abundance of krill, the interaction of krill with its predators, and the overall ecological significance of krill in the Gulf of Maine ecosystem. Like many zooplankton, the distribution of krill is notoriously variable; rather than being uniformly dispersed in space, the animals tend to be found in relatively discrete 'patches,' and their distribution and abundance fluctuate substantially over time scales varying from minutes to years. Understanding the combination of physical (e.g., currents) and biological (e.g., migrations, predator avoidance) processes that lead to this patchiness poses a fascinating and long-standing problem in biological oceanography. The formation of patches is crucial in determining the availability of zooplankton to predators: analyses of the stomach content of fin whales, for instance, has suggested that these whales could not meet their daily food requirements if their krill prey were uniformly, rather than patchily, distributed.

Historically, the study of zooplankton patchiness has been limited by a lack of tools with sufficiently high resolution to capture the variability inherent to zooplankton distributions. High frequency acoustic systems, however, allow the water column to be sampled rapidly and at high resolution as a survey vessel proceeds along its track, and are, thus, increasingly employed in the study of zooplankton such as krill. Acoustic techniques rely on the fact that many marine organisms scatter sound in a predictable manner. Measurements of the intensity of echoes returned from sonic pulses emitted into the water column, therefore, can be used to make estimates of more ecologically-meaningful quantities such as animal abundance and size. This process of estimating the abundance from acoustic measurements is not always straightforward, though, particularly in regions like the



High-resolution acoustic measurements are used to estimate abundance and size of zooplankton in the water column. The figure shows acoustic data collected at four frequencies in the Gulf of Maine. The color scale indicates the intensity of sound scattered by the zooplankton (S_v) from low (blue) to high (red), as a function of depth and time. Intensity varies, due to the patchy distribution of the animals. The differences in scattering intensity at the four frequencies result from differences in the way the various animals scatter sound, and will be used to identify those times and places where krill are found. [Figure reproduced from Lavery et al. (2007)]



Gareth Lawson

Gulf of Maine where a variety of animals are likely to be present and contributing to measurements of scattered sound. It is thus usually necessary to combine acoustic observations with other sampling methods such as nets.

With funding from the OLI, my WHOI collaborators (Andone Lavery, AOPE, Peter Wiebe, Biology), and I are analyzing data collected from a suite of advanced sensing technologies, including acoustics, nets, and video systems, to understand the causes of krill patchiness in the deep basins of the Gulf of Maine. Specifically, we are applying new multi-frequency techniques to quantify krill abundance. This method capitalizes on differences between krill and other organisms in the way they scatter sound. These estimates of krill abundance then allow us to examine spatial and inter-annual variability in the distribution, abundance, and patch structure of krill populations in relation to water



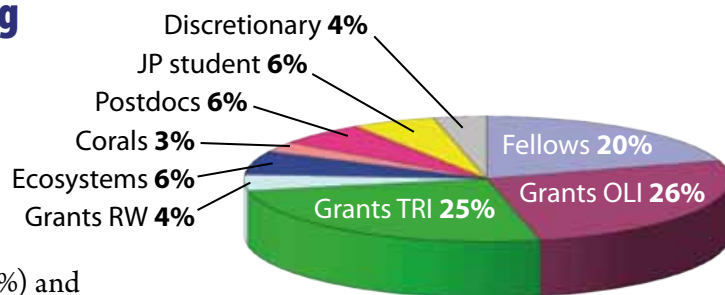
*A tiny shrimp-like species of krill called *Meganyctiphanes norvegica*, found in the Gulf of Maine is the target organism for this study. (Photo by Øystein Paulsen)*

properties and bottom topography. This project represents an essential first step toward our development of a longer-term research program aimed at understanding the ecological importance of krill in this region, and at developing new techniques for the quantification of krill abundance.

—WHOI Biologist Gareth Lawson

2008 OLI Research Spending

The total budget for OLI in 2008 was \$1,333,184, including \$339,523 for the Tropical Research Initiative which is administered by OLI. As in past years, OLI allocated the majority of its funds in 2008 to research grants (51%) and fellowships (20%), supporting dozens of WHOI scientists. Six research grants were supported through the annual OLI call for proposals (26% of total budget) and five additional grants were funded through the Tropical Research Initiative (25% of budget). The Right Whale Initiative (4%) continued to support crucial efforts to save these highly endangered species, leading to promising signs of their recovery. Funding was also used for research and development of a new WHOI project in fisheries ecosystems (6%) with modeling work done to explore observing



system designs. Development of a new research initiative in coral reef ecology was also supported (3%). Funds were provided for WHOI Postdoctoral Scholars (6%) and Joint Program PhD students (6%), fostering development of the next generation of scientists. Discretionary funding (4%) was used to support travel and research by several scientists, postdocs, and students. In addition to these budget components, a new Marine Mammal Center was established within OLI and has a separate budget.



About the Ocean Life Institute

The Ocean Life Institute (OLI) explores the oceans' extraordinary diversity of life—from microbes to whales—to identify ways to sustain healthy marine environments and to learn about the origin and evolution of life on Earth and perhaps other planetary bodies. Institute researchers pursue biological questions that affect natural ecosystems and/or human society. Our objective is to advance the understanding of marine organisms and biological processes with new technologies and approaches, to develop new opportunities for research, to convene local and national discussions on important ocean-life questions, and to communicate scientific results in a timely, objective, and effective manner to other segments of society.

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FRONT COVER: Indonesian diver behind sea fan in Raja Ampat, Indonesia, in February 2008. Photo by Cabell Davis.

BACK COVER: Tube sponges and soft corals in Raja Ampat, Indonesia, the center of the coral triangle and ocean biodiversity. Photo by Cabell Davis.