Key Concepts in Microbial Oceanography

What is Microbial Oceanography?

Microscopic organisms (or microbes) are the most abundant life forms on Earth. Microbial oceanography is the study of the abundance, distribution, growth, metabolism, and diversity of microbes in the marine environment, from coastal regions to the open ocean and from the equator to the poles.

Understanding the roles that microbes play in the cycling of nutrients in the ocean is a key component of microbial oceanography. In essence, microbial oceanography seeks to understand how microbes function in—and influence—the Earth's most dominant physical feature, the ocean.

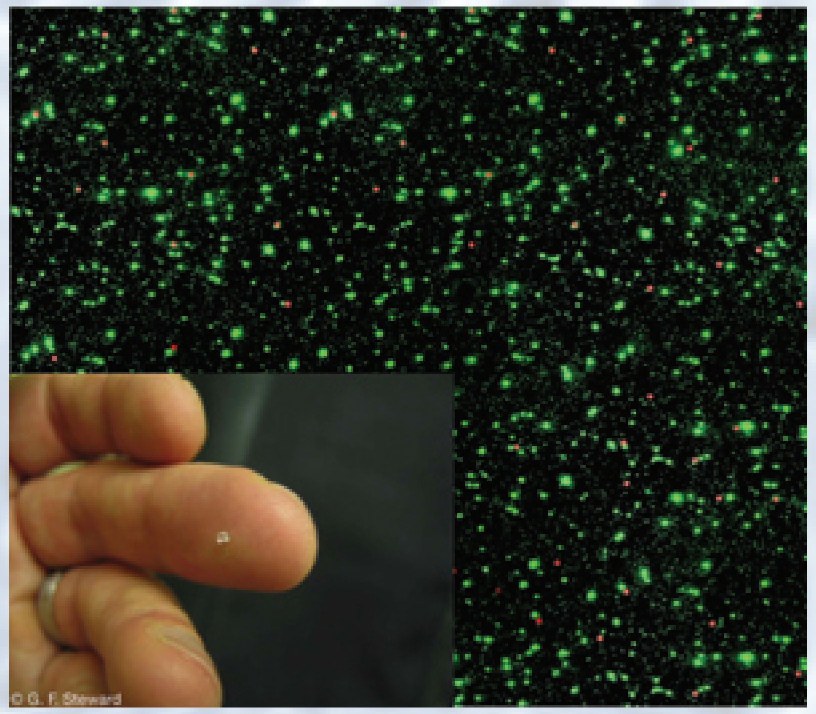
Community Living. Microbes living in coral provide nutrients and pigmentation for their host. (©Planetary Coral Reef Foundation, 1997, Michel Lippitsch)

Marine microbes are very small and have been around for a long time.

Most microbes are too small to be seen by the unaided eye, so scientists use microscopes to see them. The name *microbe* comes from the Greek *mikro* ("small") and *bios* ("life"). Microbes are so tiny that millions of them can fit on the head of a pin.

Microbes were the first life forms on Earth. Some of the oldest fossilized remains of microbes were found in the Pilbara region of Western Australia, and are estimated to be around 3.5 billion years old.

In the inset photo, the tiny cube on the finger measures 1 mm on each side and represents a volume of 1 microliter. The main photo shows the vast numbers of microbes in 1 microliter of seawater. The big red and green dots (numbering about 1,000) are bacteria, and the very small background dots (about 10,000) are viruses.



© G. F. Steward

Life on Earth could not exist without microbes.

Billions of years ago, marine microbes helped to create the ozone layer in the upper atmosphere. The ozone layer protects us by absorbing the majority of the sun's ultraviolet rays that may be harmful to life on Earth.

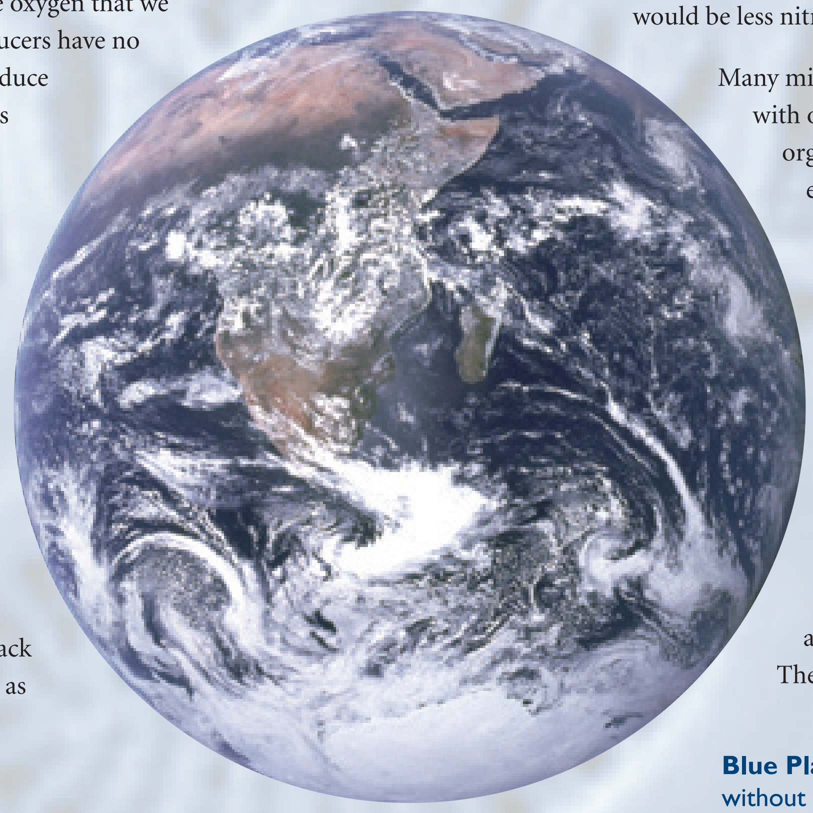
Phytoplankton produce about half of the oxygen that we breathe. These microscopic oxygen producers have no roots, stems, or leaves; however, they produce roughly as much oxygen as all land plants combined.

Microbes form the base of the marine food web. They are eaten by bigger creatures, which in turn are eaten by even larger creatures. Without microbes, none of the larger fish or marine mammals could survive.

Certain (heterotrophic) bacteria help recycle nutrients in the ocean. These decomposers break down organic matter, releasing essential nutrients that can be reused by other marine microbes and which are ultimately incorporated back into the marine food web. This is known as the microbial loop.

Microbes are largely responsible for nitrogen fixation, or converting atmospheric nitrogen into a form that is useful to all living organisms. Although nitrogen makes up almost 80% of the Earth's atmosphere, it is not in a form that most plants can use. Without microbes to "fix" nitrogen, there would be less nitrogen available for plants to grow.

Many microbes live in symbiotic relationships with other organisms. In most cases, both organisms benefit from living together. For example, zooxanthellae are photosynthetic microbes that live within and provide nutrients for many corals. Without zooxanthellae, these corals will usually die because they get up to 98% of their nutrients from these microorganisms. In turn, coral reefs provide important habitat for the zooxanthellae, as well as other marine life. Coral reefs are considered the "rain forests" of the ocean because they support a wide variety of marine life, and are a source of food and medicine. They also protect coastlines from erosion.



Blue Planet. Life on Earth would not be possible without microbes. (NASA)

Microbes are everywhere: they are extremely abundant and diverse.

Microbes are found in every ocean environment imaginable. They can thrive in the deep ocean; for example, some microbes feed on minerals deposited around hydrothermal vents. Certain microbes live inside the tissues of other animals, such as corals and clams, while others live in the ice of Antarctica.

Microbes are the most abundant and diverse biological entities in the ocean. They represent approximately 98% of the ocean's biomass. This means that if you were to add up the weights of all the whales, sharks, other fish, crustaceans, and all other visible marine life, their total weight would be considerably less than the total weight of all marine microbes. Just imagine, there are more microbes in the ocean than stars in the known universe!

Thousands of different species of microbes have been identified, and the total keeps growing as new species are continually being discovered.

Phytoplankton are autotrophic microbes that, like plants, use chlorophyll and sunlight to live and grow through a process called photosynthesis. Other marine microbes are unable to make their own food; these heterotrophs survive by absorbing organic materials from the surrounding water. Still others, such as viruses, rely on host cells to reproduce and grow.

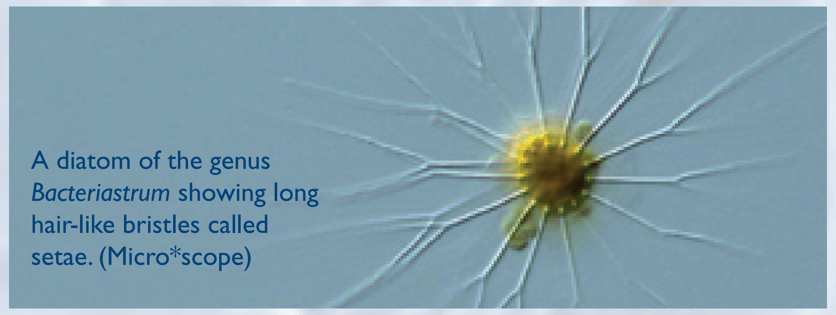
Life on Earth is classified based on evolutionary history and common ancestry.

Currently, we recognize three major groups of life on Earth: **Bacteria**, **Archaea**, and **Eukarya**.

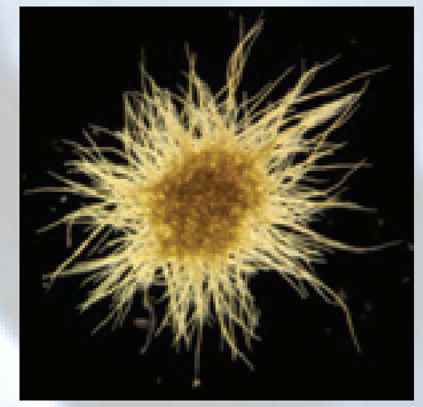
Bacteria and **Archaea** are single-celled organisms that come in a variety of shapes and sizes. They have no clearly defined nucleus to house their DNA. The combined grouping of Bacteria and Archaea is also referred to as "Prokaryotes."

All remaining unicellular organisms and all visible forms of life are termed **Eukarya** (or "Eukaryotes"), the organisms having a well-defined nucleus to house their DNA. Eukarya include many types of microbes, such as most algae (diatoms, coccolithophores, dinoflagellates) and protozoans.

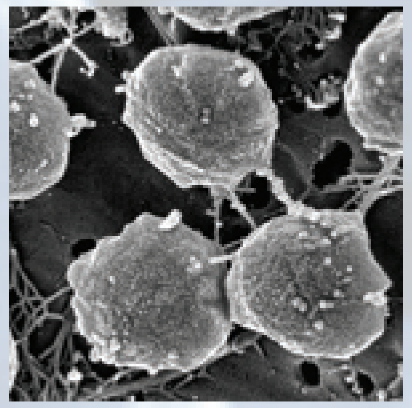
Viruses are extremely small; they are even smaller than a cell. In fact, viruses are not even alive.



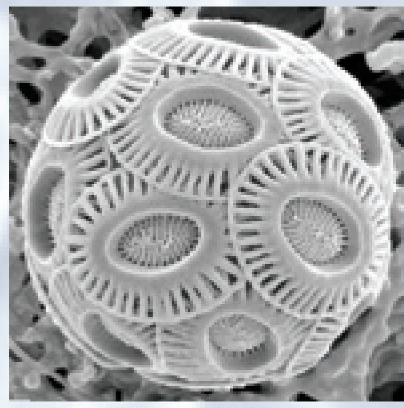
A diatom of the genus *Bacteriastrum* showing long hair-like bristles called setae. (Micro*scope)



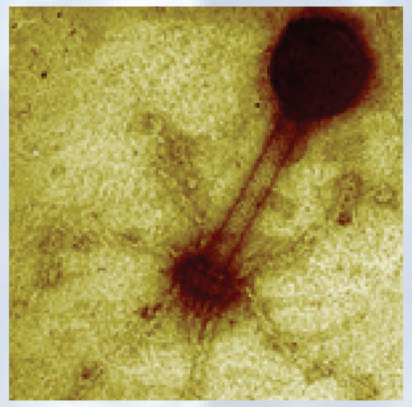
Trichodesmium is a photosynthetic bacterium, or cyanobacterium, that changes atmospheric nitrogen into a form that is usable by other organisms. It can form algal blooms that cover large areas of the ocean surface. These blooms can even be seen from space. (Micro*scope)



Methanococcus jannaschii was the first archaeon to have its genome fully sequenced. Some *Methanococcus* species can be found living near hydrothermal vents, where water temperatures can be extremely high. (Electron Microscope Lab, UC Berkeley)



Coccolithophores are single-celled protists that form a shell of small plates called coccoliths. The remains of these shells help to make up the sand found on many beaches. (Micro*scope)



Synechococcus phage is one of the many viruses found in our oceans. (Micro*scope)

Microbes significantly impact our global climate.

Microbes help to maintain our global climate by regulating carbon dioxide (CO_2) levels in the atmosphere. By burning fossil fuels, humans put billions of tons of CO_2 in the atmosphere each year. Marine microbes remove a significant portion of the CO_2 that we place in the atmosphere each year, which is critical in curbing human-induced climate change.

Clouds over the Pacific Ocean. Microbes contribute to the formation of clouds over the Earth's oceans.

Microbes contribute to cloud development over the ocean by producing dimethyl sulfide (DMS) gas. DMS helps form particles, around which clouds develop. So, microbes are partly responsible for regulating the water cycle. In addition, clouds help to deflect sunlight, so marine microbes also help to keep our planet cool.

Most marine microbes are beneficial.

Marine microbes are a largely untapped resource that could yield benefits in medicine and technology.

Microbes are used to clean up certain environmental pollutants through a process called bioremediation. For example, *Oceanospirillum sp.* were used to clean up the 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska.

The oil and natural gas that we use to heat and cool our homes and run our cars are the remains and by-products of ancient microbes buried deep in the earth. This is why they are called fossil fuels.

Viruses help to recycle organic matter by breaking up cells. The resulting cell fragments can then be consumed by other micro-organisms for energy.

Only a small percentage of marine microbes are actually harmful. For example, some microbes cause Harmful Algal Blooms (HABs), such as red tide, which can make shellfish toxic and can poison fish.

Cleaning up. Bacteria are being tested for use as cleaning agents of toxic chemicals and pollutants in our environment. (JGI)

center for microbial oceanography: research and education

C-MORE *linking genomes to biomes*

cmore.soest.hawaii.edu

There are new discoveries every day in the field of microbial oceanography.

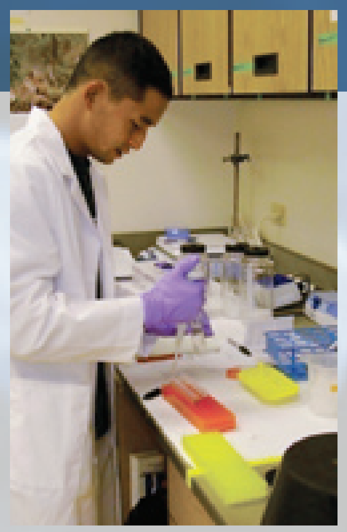
Marine microbes were the first life forms on Earth, yet much of the marine microbial community has yet to be described. Only a small percentage of the microbes that have been discovered have been cultured or grown in a lab. As a result, scientists are continually trying to develop new and effective ways to grow and study microbes.

It is estimated that fewer than 1% of the bacteria in the ocean have been cultured. This means that a wealth of discoveries await future microbial oceanographers. *Pelagibacter ubique* is currently believed to be the most abundant organism on Earth, and it was just isolated in 2002!

Science at sea. The research vessel *Kilo Moana* (near right). Scientist recovering a water sample from the deep ocean (far right).

Unless otherwise noted, all images are courtesy of C-MORE.

Brenner Wai



Brenner at work in the lab.

Undergraduate Student Research Assistant

University of Hawaiʻi at Mānoa

Describe your research.
I study micro-organisms involved in chemical processes in the world's oceans.

Why is your research important?
We can answer questions that help people to gain a better understanding of the world in which we live.

How did you get interested in microbial oceanography?
My appreciation for nature, love for the ocean, and the inquisitive nature of being a scientist attracted me to the field of microbial oceanography.

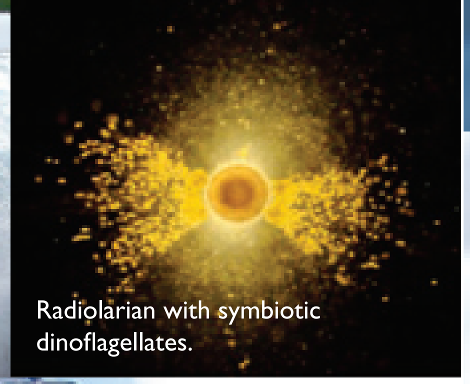
What is the coolest experience you have had on the job or during your studies?
I think it is very cool being able to converse with some of the university's smartest scientists. They watch over me, because they are my highly esteemed mentors and life long friends.

What is your favorite microbe?
Diatoms. These silica-based organisms are very beautiful to look at under the microscope.

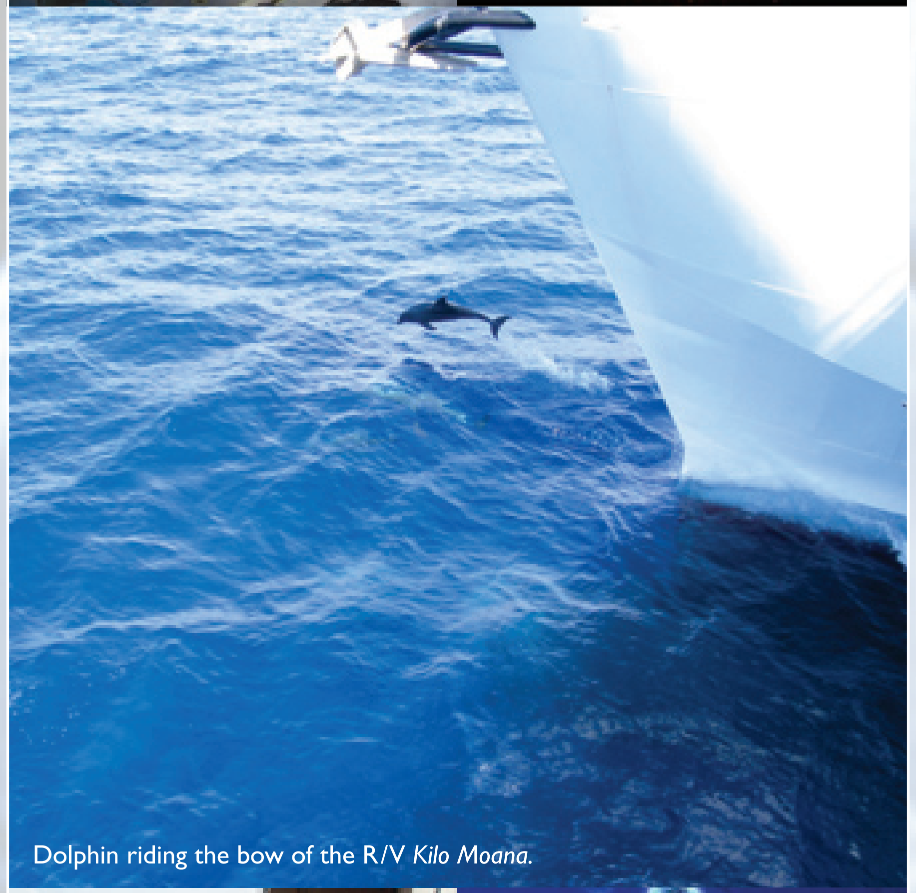
What is your favorite work related activity?
My favorite work related activity is learning new methods in a genetics laboratory.

If you had to give advice to someone who wanted to become a microbial oceanographer, what would it be?
If you want a career in microbial oceanography, I recommend gaining research experience now. Trust me, this is fascinating stuff!

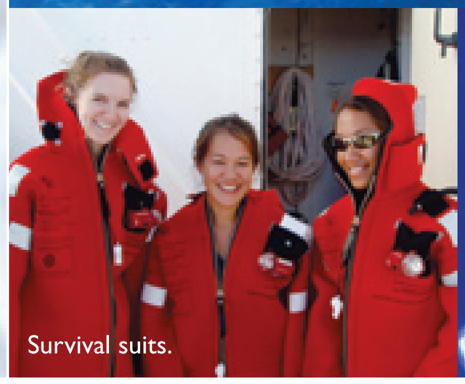
Stern of the R/V *Kaʻimikai-O-Kanaloa.*



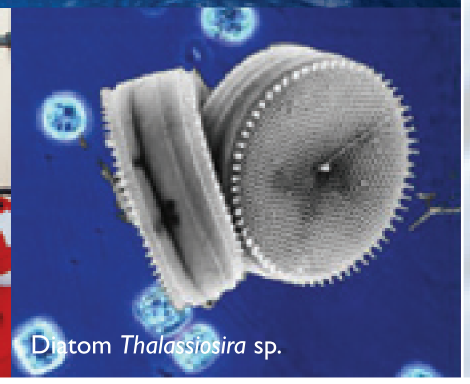
Radiolarian with symbiotic dinoflagellates.



Dolphin riding the bow of the R/V *Kilo Moana.*



Survival suits.



Diatom *Thalassiosira* sp.

Jamie Becker

Jamie on a research ship near New Caledonia.

Graduate Student

Massachusetts Institute of Technology and Woods Hole Oceanographic Institution Joint Program

Describe your research.
I am working to identify the major compounds that make up dissolved organic matter in the oceans and trying to determine which marine microbes produce and consume these compounds.

Why is your research important?
Information regarding nutrient cycling in the oceans is vital to our understanding of the Earth's climate.

How did you get interested in microbial oceanography?
I loved the ocean growing up and have always been amazed by how little we know about something that covers almost 75% of our planet's surface. There is so much room for discovery in microbial oceanography.

What is the coolest experience you have had on the job or during your studies?
The coolest experience I have had so far on the job was on a research cruise in the Pacific where I was a passenger in the ALVIN submersible and traveled almost two miles down to the bottom of the ocean. The experience was unlike anything I had ever done before.

What is your favorite work related activity?
My favorite work activity is conducting research at sea on research vessels. My work has already taken me to amazing places around the globe that I most likely would never have visited otherwise including Hawaiʻi, Australia, New Caledonia, and Fiji.

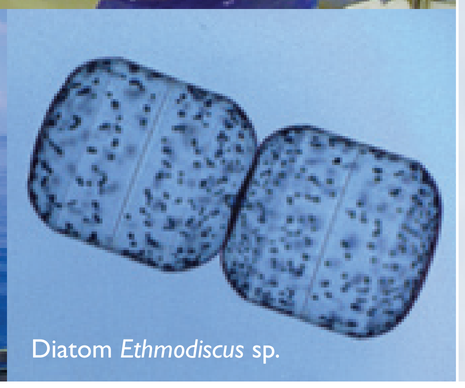
What are some of the challenges you face in your research?
Scientists have to figure out new ways to answer difficult questions. A failed experiment is a challenge that scientists must overcome through creativity and perseverance.

Sediment trap deployment.

Dinoflagellate *Protoperidinium pellucidum.*

C-MORE intern conducting research.

Deploying a water sampler.



Diatom *Ethmodiscus* sp.

Rachel Foster

Rachel at the ceremonial South Pole.

Postdoctoral Scholar

University of California Santa Cruz

Describe your research.
I mostly research the distribution, diversity, and physiological activity of cyanobacteria. I am particularly interested in symbioses (when two or more organisms live together in close association), especially when one of the partners is a cyanobacterium.

What is your favorite microbe?
My favorite microbe is *Richelia intracellularis*, which is a cyanobacterium commonly found as a symbiont of open ocean diatoms. Generally though, I like studying cyanobacteria because they are ancient, they were responsible for oxygenating the planet, and they were also the precursor to the chloroplast.

What is the coolest experience you have had on the job or during your studies?
I participated in the Antarctica Biological Training Course at McMurdo Base when I was a graduate student. While I was in Antarctica, I had the opportunity to join my advisor on a research excursion to the South Pole to help him study bacterial respiration. I was at the South Pole for six hours, and the thought that I was standing on the bottom of the Earth was an amazing feeling that I will never forget. Also, the flight down followed the path taken by the early explorers, and it was the most spectacular and most untouched landscape I have ever seen.

If you had to give advice to someone who wanted to become a microbial oceanographer, what would it be?
My advice would be to parallel one's research with the advancements in bioinformatics. The field is growing fast and expanding in a more molecular direction; having the tools of a field oceanographer with the genomic analyses will be instrumental for the future of microbial oceanographers.

Workboat.

Diatom *Chaetoceros densus.*

Preparing the Conductivity, Temperature, and Depth (CTD) array for deployment.

Sediment trap.

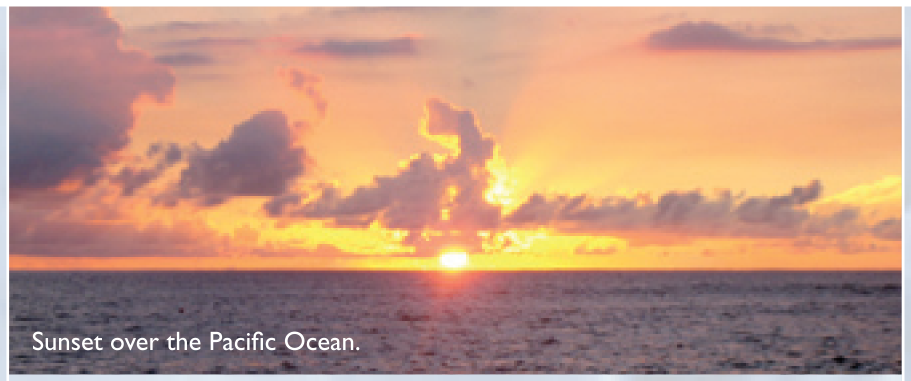
Diatom *Asterionellopsis glacialis.*

C-MORE

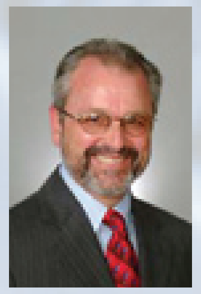
The Center for Microbial Oceanography: Research and Education (C-MORE) was established in 2006 by the National Science Foundation (NSF). The center is comprised of six institutions that are leaders in the field of microbial oceanography: Massachusetts Institute of Technology (MIT), Monterey Bay Aquarium Research Institute (MBARI), Oregon State University (OSU), University of California Santa Cruz (UCSC), Woods Hole Oceanographic Institution (WHOI), and our headquarters, the University of Hawaiʻi at Mānoa (UHM).

Research. Our overarching goal is captured in the C-MORE motto "From genomes to biomes", meaning that our research explores how microbial diversity at the genomic level influences the structure and function of the world's largest biome, the global ocean. C-MORE researchers seek to understand processes that begin at microscopic scales and ultimately are expressed in vitally significant, global environmental issues such as climate change. Areas of research range from genomic surveys, to studies of the genetic basis of marine microbial biogeochemistry, to ecosystem modeling. C-MORE research emphasizes integrative, interdisciplinary studies that truly range from the microscopic to global in scale.

Education and Outreach. The C-MORE education and outreach program is focused on increasing scientific literacy in microbial oceanography, and providing the best possible training for the next generation of microbial oceanographers. C-MORE offers a variety of resources and professional development opportunities for K–12 teachers and informal science educators, including online resources, oceanography research cruises, teacher-training workshops, and mini-grants to incorporate microbial science into their curriculum. For undergraduates, C-MORE offers internships at all six partner institutions. C-MORE also supports a state-of-the-art summer course at the University of Hawaiʻi for graduate students and postdoctoral scholars. For more information, please visit **cmore.soest.hawaii.edu** and click on "Education and Outreach".



Sunset over the Pacific Ocean.



David Karl
Director of C-MORE

Marine microbes dominate the ocean and sustain planetary habitability. Louis Pasteur noted many years ago, "The very great is achieved by the very small" and he was absolutely correct.

The Center for Microbial Oceanography: Research and Education (C-MORE) was established to explore the largely unknown and fascinating world of sea microbes, to build partnerships between scientists and educators, to prepare the next generation of microbial oceanographers, and to facilitate outreach to the public at large. We have an excellent team in place and we are already making great progress towards our stated goals.

C-MORE research cruise.

Credits

The creation of this brochure was a collaborative effort that included input from numerous faculty, graduate students, and postdoctoral scholars at the Center for Microbial Oceanography: Research and Education. The following people from the University of Hawaiʻi at Mānoa were responsible for the development of this guide.

- Kate Achilles
- Barbara Bruno
- Gordon Walker
- Kimberley Weersing

Other contributors

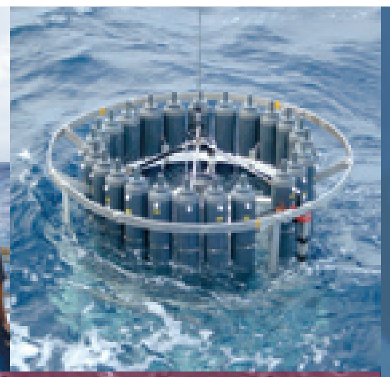
- Jamie Becker, WHOI
- Penny Chisholm, MIT
- Alexander Culley, UHM
- Adrienne Dolberry, MIT
- Ken Doggett, UHM
- Jennifer Edmonds, UHM
- Alexander Eiler, UHM
- Allison Fong, UHM
- Rachel Foster, UCSC
- Darin Hayakawa, UHM
- David Karl, UHM
- Paul Kemp, UHM
- Nikki Lawrence, Santa Cruz Boardwalk
- Binglin Li, UHM
- Sarah Mansergh, UCSC and Monterey Bay Aquarium
- Mark McCaffrey, CIRES
- Pia Moisander, UCSC
- Mar Nieto-Cid, WHOI
- Noelani Puniwai, UHM
- Anne Thompson, MIT
- Brenner Wai, UHM
- Sam Wilson, UHM

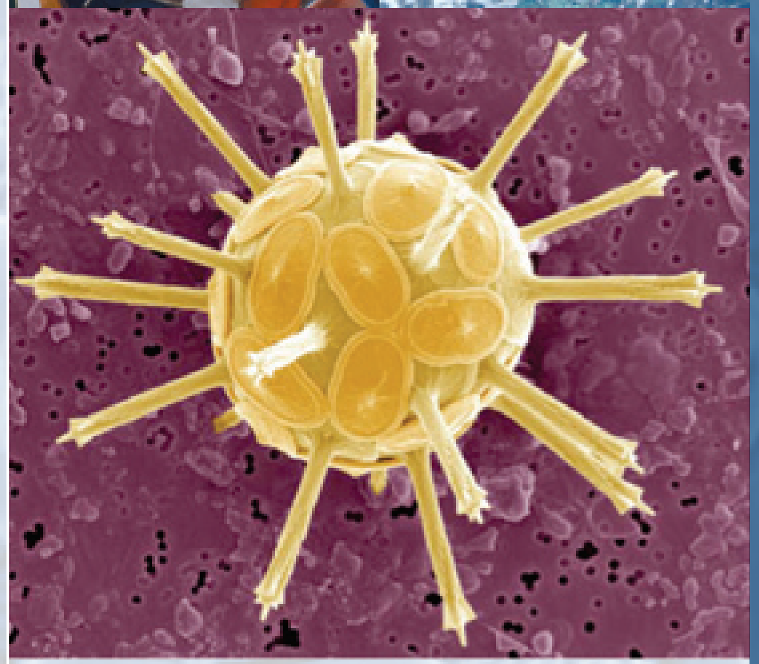
c·more
center for microbial oceanography: research and education

Layout and design by Brooks Bays, SOEST Publication Services, UHM

All microbe images on this side (except for the diatom *Ethmodiscus*) are courtesy of Micro*scope. Unless otherwise noted, all other images are courtesy of C-MORE.

National Science Foundation





c·more

CENTER FOR

microbial oceanography: research and education

cmore.soest.hawaii.edu

Key Concepts in Microbial Oceanography