Ripple Marks
The Story Behind the Story

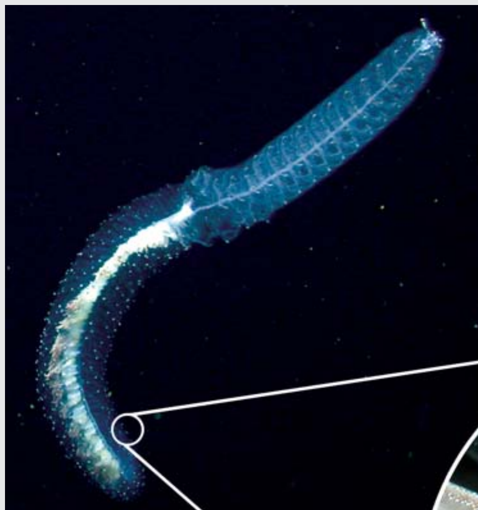
BY CHERYL LYN DYBAS

THE RED LIGHT DISTRICT

THE RED LIGHT DISTRICT IS LOCATED NOT ON A SEEDY SIDE STREET IN A MAJOR CITY, BUT, OCEANOGRAPHERS HAVE DISCOVERED, IN THE DEEP SEA. Animals that live in the sea's abyss produce and perceive red light, contrary to what was the prevailing view among marine biologists: that most deep-sea animals can't detect red light at all.

Research by Steven Haddock of the Monterey Bay Aquarium Research Institute (MBARI) and colleagues Bruce Robison and Kim Reisenbichler, as well as Edie Widder, formerly of Florida's Harbor Branch Oceanographic Institution and now of the Ocean Research and Conservation Association in Fort Pierce, Florida, shows that some deep-sea fishes not only see red light, but use it in locating prey.

As Haddock reports in a paper in the journal *Science* (July 8, 2005), siphonophores—colonial hydrozoans that can reach tens of meters long—in the genus *Erenna* are forcing scientists to take another look at red light in the deep sea. *Erenna* sports thin rod-like structures between its stinging tentacles. These "tentilla" are tipped with red, glowing beads, the better to lure in small deep-sea fish. In looking at *Erenna*'s gut contents, said Haddock, there were enough fish for the siphonophores to survive in a sparsely inhabited environment 2,000 m deep.



This newly discovered deep-sea siphonophore is about 45 cm (18 inches) long. The upper half of the colony moves it through the water. The lower half carries pale white stinging tentacles and red, glowing lures that are used to capture small deep-sea fish. Photo credit: © 2003 MBARI. Close up view of the lures and tentilla. Photo credit: Steven Haddock © 2004 MBARI.

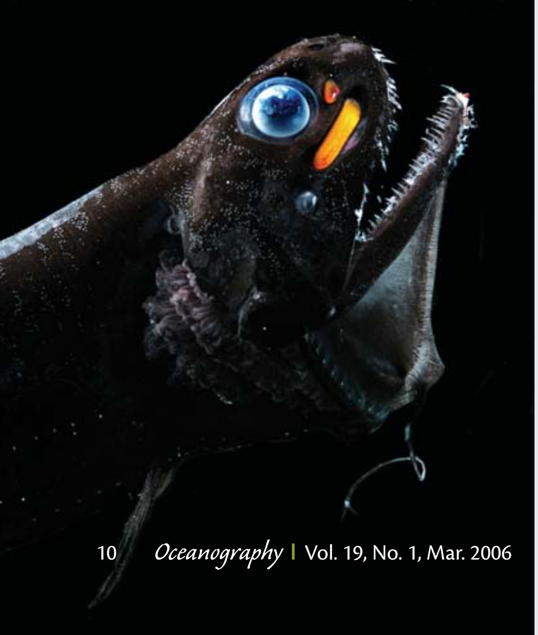
The red lures are on stalks that move up and down, causing them to wiggle like swimming copepods, a typical food of small deep-sea fishes. *Erenna*, it appears, is mimicking copepods so the fish will swim ever closer to the siphonophore's stinging tentacles.

"This is at odds with the prevailing view that deep-living creatures cannot detect these wavelengths," wrote Haddock in *Science*. "However, our knowledge of deep-sea visual abilities is limited."

For *Erenna*'s ruse to work, its fish prey need to perceive red light, said Widder, who has devised a means of testing that ability. She and Robison, Reisenbichler, and Haddock published a paper in the August 2005 issue of *Deep-Sea Research* on use of a camera system called Eye-In-The-Sea (EITS). EITS uses dim red light to study life in the deep sea, including fishes like those *Erenna* catches.

"Our primary means of viewing animals in the deep ocean has required the use of bright incandescent lamps disruptive to the life processes of animals that live there," said Widder. "Animals capable of swimming often flee from the lamps or swarm around them." Sedentary animals shrink back, stopping their normal activities, and animals with sensitive eyes may be permanently blinded.

"To really understand life in the oceans," she believes, "we must find ways to study oceanic communities and populations without modifying their habitat and frightening them with intrusive, artificial lights." On land, this is done with infrared illumination, which is invisible to animals being observed, but visible to infrared cameras recording their behavior. In the ocean, explains Widder, infrared light is attenuated so quickly that observations usually are restricted to distances of less than a few meters.

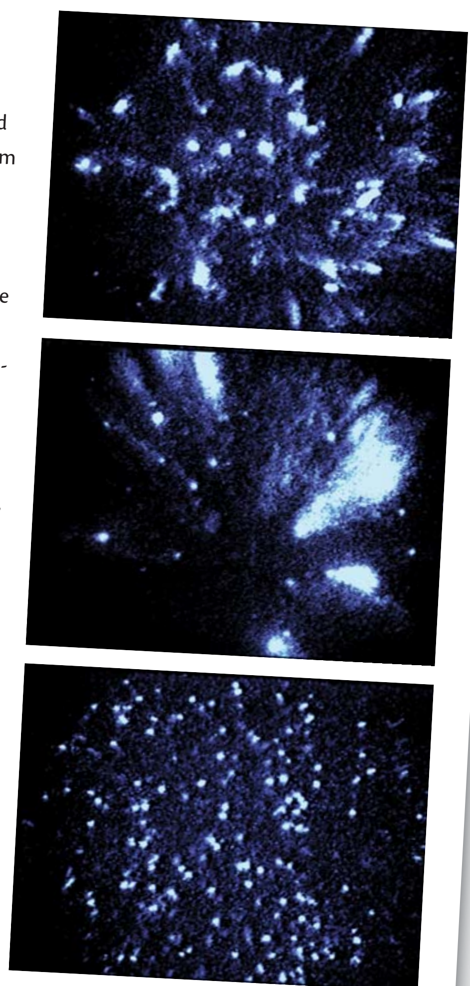


Pachystomias microdon: one of the very rare dragonfish which were, until recently, the only known marine organisms to produce red luminescence. Photo credit: Edith Widder, Ocean Research & Conservation Association.

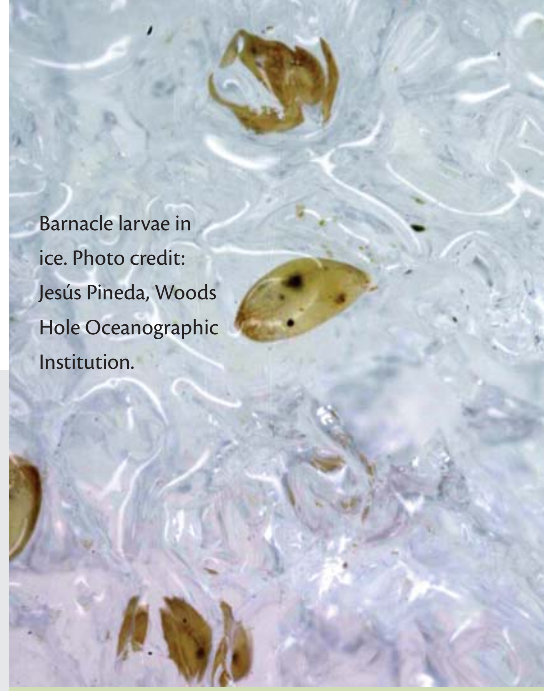
In *Deep-Sea Research*, Widder describes *in situ* observations of fish behavior viewed with far-red illumination combined with low-light-level cameras that can compensate for attenuation losses.

Widder attached a bait box to the EITS camera and lowered it to the depths of Monterey Bay aboard MBARI's remotely operated vehicle *Ventana*. "When we compared the number of 'on camera' appearances of sablefish (*Anoplopoma fimbria*) under red light to those under white light, the number was significantly greater under red light," said Widder. When red light was alternated with white light at 10-minute-intervals, she said, "the fish rushed in when red light was turned on, and then dispersed quickly when we switched over to white light."

The role of red light in marine ecology merits a much closer look, said Widder. "We should use red light," she maintains, "whenever possible to get a better view of deep-sea animals such as fishes." Lurking soundlessly in the deeps, *Erenna* would doubtless agree.



Bioluminescence has been recorded *in situ* using an intensified video camera, focused on a large-mesh transect screen mounted on a mid-water submersible. The spatial and temporal patterns of the light emissions from different organisms are distinctive enough that they can be used to identify and map plankton distribution patterns. The intensified camera records in black and white. These images have been colorized to match the spectral distribution of the luminescent emissions. In these frames, which were recorded in the Gulf of Maine, the field of view is 1 m across. In the top image, small clouds of light are produced by the copepod *Metridia lucens*, which releases its luminescent chemicals into the water to distract a predator as it escapes. A similar strategy is used by the ctenophore *Euplokamis* sp., which releases large clouds of luminescent particles into the water as seen in the middle image. Bioluminescent dinoflagellates, which are the dominant source of luminescence seen in the bottom image, are recognized by their small short flashes. In this case, based on samples collected during the submersible transect, these displays were identified as the dinoflagellate *Protoperidinium depressum*. Courtesy of Edith Widder, Ocean Research & Conservation Association.



Barnacle larvae in ice. Photo credit: Jesús Pineda, Woods Hole Oceanographic Institution.

UNEXPECTED CATCH

NEW ENGLAND INTERTIDAL ZONE SERVES UP UNEXPECTED CATCH

Q: Why did the barnacle settle on ice?

A: To establish a population where few other species could succeed. (Or might want to.)

As biological oceanographer Jesús Pineda of the Woods Hole Oceanographic Institution and his colleagues discovered, living on sea ice is no joke for barnacles of the species *Semibalanus balanoides*. Like anywhere on a crowded planet, the key to happy homeownership is location, location, location.

In the winter of 2003, Pineda's research associates Claudio DiBacco and Vicke Starczak braved the elements to take seawater samples along Rhode Island shores. In the frozen New England waters, they found unexpected life: barnacle larvae embedded in intertidal ice.

The researchers later placed the barnacle larvae in (comparatively warm) water, where the larvae revived, swam around, and eventually reproduced. "Ice was always thought to be an obstacle to any larva that didn't find its niche before winter set in," said Pineda. "As far as we were concerned, that larva was a goner. Clearly we have to do some rethinking."

Tiny drifting larvae of marine animals like barnacles hitch a ride on the ocean's currents and tides, eventually arriving somewhere they can settle down and mature into adults.

Semibalanus balanoides, an abundant and ecologically important intertidal species throughout North Atlantic rocky shores, reproduces by releasing larvae that feed on plankton in the water column. For a while, the larvae live in bays and open coastal waters; they molt five times before metamorphosing into non-feeding larvae and returning to shore, where they settle more permanently onto a piece of intertidal real estate.

S. balanoides larval settlement in Woods Hole, Massachusetts, coincides with the coldest water and air temperatures of the winter and early spring, said Pineda. "Freezing air temperatures along northeastern U.S. shores are common, leading to frequent sea ice formation there, something these barnacles have to contend with."

Like human Yankees, barnacles come from hardy stock: their larvae, Pineda found, can survive for more than four weeks stuck onto sea ice, and many of them, once thawed out, successfully reproduce.

Sea ice piled up along Rhode Island and Massachusetts shores, it turns out, is an ideal habitat for barnacles, one where no other creature is competing for space.

"Freezing tolerance in barnacles likely explains this species' widespread range, and suggests that it survived the last glaciation in the western Atlantic Ocean," said Pineda.

Understanding species distributions, including responses to global climate change, species redistributions after major biogeographic events, and survival in extreme environments, requires developing an understanding of how environmental stresses constrain population abundance and distribution, wrote Pineda in a paper on the frozen barnacles published in the September 2005 issue of the journal *Limnology and Oceanography*. "Stress-tolerant larvae capable of colonizing variable environments might confer advantages for the population and, in the long run, prevent local extinction."

Sea ice might also ferry barnacle larvae to a far shore: larvae in ice would follow different dispersal pathways than free-swimming larvae, Pineda believes, because floating ice blown about by winter winds follows different trajectories than seawater. For a barnacle, that might be just the ticket.

ONCE MOUNTAIN ICE, NOW COLD SEAWATER

HISTORICAL COMPARISON OF ALASKA'S GLACIERS SHOWS THEIR RAPID DISAPPEARANCE. Glacier Bay, Alaska, soon may be hard to find—if you're looking for its namesake glacier.

Historical photographs of Glacier Bay, taken as early as the mid-1880s, are being used to compare the extent of the bay's glacier then, to its extent now. The news for Alaska's glaciers, said marine geologist Bruce Molnia of the U.S. Geological Survey in Reston, Virginia, is not good. "Alaska has about 2,000 glaciers, some 700 of which are named," said Molnia. "Fewer than 20 are still advancing."

Alaska's climate is changing, said Molnia in a talk at the American Geophysical Union (AGU) conference in December 2005. "One of the most significant indications of this change has been the late-nineteenth to early-twenty-first century retreat of glaciers."

Weather station temperature data document increasing air temperatures throughout Alaska over the past several decades. Since the mid-twentieth century, the average change is an increase of about 2.0 degrees centigrade.

To determine glaciers' response to regional climate change, Molnia and colleagues are studying hundreds of glaciers located in Alaska. "We're analyzing data from maps, historical observations, and thousands of ground and aerial photographs and satellite images."

In areas below an elevation of 1,500 m, "virtually every glacier is retreating, thinning or stagnating," said Molnia. "In all, this represents more than 98 percent of Alaska's glaciers."

The results are most striking, Molnia believes, when comparing historical and present-day images of glacier-covered areas. "We decided that the best way of illustrating what's happened is to go to locations where photographs of glaciers were taken in the past, and take new images. If you look at these pairs of photos side-by-side—the before and after, if you will—the changes are incredible."

The image shown here is but a sample of the photographs Molnia has catalogued. He finds historical images of Alaska's glaciers in the archives of the National Snow and Ice Data Center in Boulder, Colorado, on old postcards, on eBay, "and anywhere else I can locate them," he said.

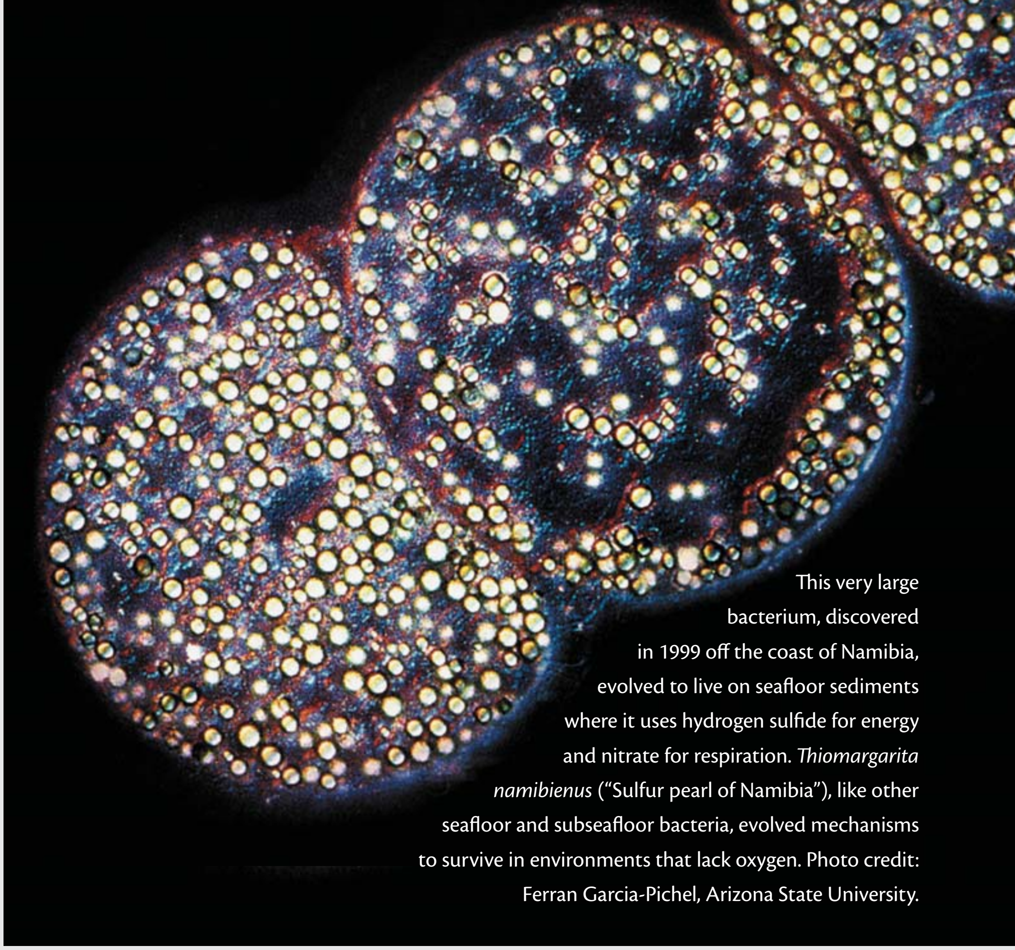
Slowly melting away are such Alaskan glaciers as Tazlina Glacier, Stephens Glacier, Wortmanns Glacier, and Cleve Creek Glacier, all located in the Chugach Mountains.

Retreating glaciers in the Chugach Mountains, Alaska. Photo credit: Bruce F. Molnia, USGS.

When European explorers first sailed along the Alaskan coastline in the 1790s, Glacier Bay was only a small embayment. Most of the bay was covered by glacial ice. "By the 1880s, the glacier had already retreated, leaving an indentation nearly 40 miles inland," said Molnia.

Glacier Bay's glacier has continued to melt, leaving more open water than ice. The bay now extends more than 60 miles into the Alaskan coastline. Decades from now, Glacier Bay's name may be but an anachronism, its glacier gone, nothing left to mark its presence but a formation on shore: glacial moraine.

DARK ENERGY



This very large bacterium, discovered in 1999 off the coast of Namibia, evolved to live on seafloor sediments where it uses hydrogen sulfide for energy and nitrate for respiration. *Thiomargarita namibienus* ("Sulfur pearl of Namibia"), like other seafloor and subseafloor bacteria, evolved mechanisms to survive in environments that lack oxygen. Photo credit: Ferran Garcia-Pichel, Arizona State University.

LIFE BENEATH THE OCEAN FLOOR POINTS THE WAY TO OUTER SPACE. "Who in his wildest dreams could have imagined that, beneath the crust of our earth, there could exist a real ocean... a sea that has given shelter to species unknown?" So wrote Jules Verne in *A Journey to the Center of the Earth*.

Indeed, as Verne suspected, life exists under the ocean floor, although perhaps not quite at the center of the earth. Scientists like Steven D'Hondt of the University of Rhode Island Graduate School of Oceanography and his colleagues have found microbes in deep, dark sediments under the seas.

To learn more about this subsurface biosphere, D'Hondt and colleagues retrieved samples of marine sediments buried beneath the equatorial Pacific Ocean and on the continental margin of Peru on Ocean Drilling Program (ODP) Leg 201. The U.S. National Science Foundation provided the principal funding for D'Hondt's ODP research.

Sites D'Hondt sampled on Leg 201 are typical of subsurface marine environments throughout the world's oceans. Water depths ranged from 150 m on the Peru Shelf to 5,300 m in the Peru Trench. Sediments were cored from subseafloor depths up to 420 m. "We found microbes throughout the sediment column at every site we sampled," said D'Hondt.

"Dark Energy," it's called, this life below the ocean's photic zone. Deeply buried sediments are just one of many oceanic dark environments. Others are found in such places as cold seeps and methane hydrates, where the energy sources for chemosynthetic bacteria are methane and hydrogen sulfide; the oxygen-minimum zone, with its nitrogen-cycling microorganisms; and mid and deep waters with planktonic archaea and bacteria.

Through sediments recovered on Leg 201, scientists studying the ocean's dark energy are trying to answer such questions as: Who lives in dark energy environments? How many are there? And, how did they get there? Answering these questions, say D'Hondt and others, requires refining currently available molecular tools and combining them with biogeochemical methods like lipid biomarkers; taking measurements of process rates like those involved in sulfate reduction; and characterizing geochemical parameters through the use of microsensors in these deep, dark places.

What now seems clear, said D'Hondt, is that life in deeply buried sediments is in a continual near-death-experience state. "If all the cells found in Leg 201 subsurface sediment samples are indeed alive, their metabolism functions at a rate 1/100,000th that of the least active microbes in near-shore sediments," said D'Hondt. "These things are taking very few breaths, very rarely, it appears."

Far from dissuading oceanographers from exploring the ocean subsurface for signs of life, findings from Leg 201 have spurred on astrobiologists, scientists who hope that developing an understanding of life in extreme environments on Earth will help in the search for life on other planets.

"Insights into life's ability to survive in conditions like those in deeply buried sediments will give us something to go on in our search for extraterrestrial life," said D'Hondt. In fact, URI is the site of one of 16 NASA Astrobiology Institutes designed to do just that.

Results from ODP Leg 201 point to some new directions for that search. D'Hondt and colleagues found unsuspected sources of microbial metabolites in Leg 201 sediments. These results were published in the December 24, 2004 issue of the journal *Science*. Oxidants that usually drift downward from overlying seawater appear to have found their way into these sediments from subseafloor sources. Several cores show evidence of sulfates that originated from brines below the sediment base, and of nitrate and oxygen coming from deep basaltic aquifers underneath the sediments.

"This situation produces 'upside-down' redox reaction profiles," said scientist Ed DeLong of MIT, "with atypical sources from beneath sediments providing oxidants such as sulfate and nitrate that enable microbes to respire anaerobically. D'Hondt and colleagues' work shows that microorganisms in the deep subsurface differ substantially from microorganisms in shallow near-surface environments." Even for Jules Verne, truth might be stranger than fiction.

Cheryl Lyn Dybas (cdybas@nsf.gov) is a staff member in the U.S. National Science Foundation's Office of the Director and is a marine scientist and policy analyst by training. She also writes on a freelance basis about the seas for *The Washington Post*, *BioScience*, *National Wildlife*, and many other publications. Ripple Marks is a new department in *Oceanography* intended to provide readers with "the story behind the story."