COURTESY: GEORGE MATSUMOTO, MBARI

"The sea isn't a place but a fact, and a mystery," wrote the Pulitzer Prize-winning poet Mary Oliver in her 1986 poem *The Waves*. Massive and mysterious, the ocean has long fascinated humanity. Despite centuries of study, these vast bodies of water have retained their inscrutable qualities, eluding the best scientific efforts to understand their deepest secrets. But on a cloudy morning on an industrial waterfront in Moss Landing, California, a technician is working on a sophisticated tool that may help decipher some of the ocean's mysteries.

In a large garage, Knute Brekke is preparing the ROV *Ventana* for another mile-deep dive into the waters of Monterey Bay. About the size and shape of a Volkswagen Beetle and topped with a tangerine-colored foam shell, the *Ventana* is a remote-controlled research vehicle that has logged more than 2,000 missions deep beneath the ocean's surface. Right now, though, the *Ventana* is on dry land while Brekke, one of the vessel's pilots and technicians, works on its "toolsled," the removable set of customized research equipment that rides on the *Ventana*'s underside. A thick yellow cable, attached to the *Ventana* at one end, snakes out the door

# DEEP SCIENCE

**Twenty-first century technology is enabling scientists to decipher the ocean's secrets**

**By Paul Clarke**

BRANDON D. COLE

**TOP: DEEP-DWELLING ANIMALS SUCH AS *VITRELEDONELLA*, A TRANSPARENT OCTOPUS, CAN BE STUDIED BY USING REMOTELY OPERATED VEHICLES (ROVS). ABOVE: LARGE PELAGICS, SUCH AS HUMPBACK WHALES, ARE THE FOCUS OF A PILOT PROJECT OF THE CENSUS OF MARINE LIFE.**

and across the street, then rises up to the deck of the R/V *Point Lobos*, the host ship, floating at dockside.

"Space is easy, as compared to the ocean," says Debbie Nail Meyer, a research technician with the Monterey Bay Aquarium Research Institute (MBARI). A private research institution that operates the *Point Lobos* and *Ventana*, along with several other ships and undersea vehicles, MBARI has sent these vessels on thousands of missions into some of the planet's deepest waters. On these dives, the vehicles endure conditions so strenuous, they're without comparison on land, while gathering data on the oceans, their ecosystems and the ways they affect life on Earth. "Space isn't opaque to radio frequencies, and you don't have to deal with saltwater or hundreds of atmospheres of pressure," Meyer says. "The ocean is a really hard place to put instruments."

COURTESY: MARV WHITE, MBARI (LEFT); KEVIN RASKOFF, MBARI

**Above left: The *Ventana*, an ROV operated by the Monterey Bay Aquarium Research Institute (MBARI), is brought onboard the R/V *Point Lobos* after a dive in Monterey Bay. Above right: *Aequorea*, a jelly found in Monterey Bay, glows with a bioluminescent protein.**

Even over the last century, while humans were mastering flight, decoding the human genome and entering the realms of space, the ocean remained relatively unexplored. But thanks to renewed global efforts to study the ocean, combined with a revolution in research technology, the vast waters that cover much of the globe are now slowly giving up their secrets. Research projects such as those at MBARI, and at universities and institutions worldwide, are utilizing these new technologies to study marine animals and ecosystems in projects unimaginable a generation ago.

Remotely operated vehicles (ROVs) such as the *Ventana* and the *Tiburon*, MBARI's other ROV, are examples of this technology. "ROVs have enabled us to spend a lot more time in the water, exploring more of the ocean," says George Matsumoto, a senior education and research specialist at MBARI. "And with ROVs, we can do a lot of this research without disturbing the animals."

The *Ventana*, MBARI's first ROV, is fitted with instruments for measuring the ocean's salinity, temperature and depth, and is mounted with an HDTV camera for relaying broadcast-quality images back to the *Point Lobos* (live feeds are also relayed to the Monterey Bay Aquarium for public programs). Detachable toolsleds enable the *Ventana* to be customized for particular missions—there's a toolsled with a rock drill, for excavating solid core samples from the walls of undersea canyons, and another toolsled that can suction fragile aquatic animals into a collection canister, allowing for the live capture of delicate creatures. The *Ventana* is always connected to the *Point Lobos* by a 7,000-foot cable that relays power and commands to the vehicle, and video images back to the pilot and researchers, who guide the ROV from a windowless control room on the *Point Lobos*. The *Ventana* is capable of diving up to 1,850 meters—more than a mile—and is typically used on day trips into Monterey Bay. The *Tiburon*, based on the R/V *Western Flyer*, debuted in 1997 for use on longer missions, and is capable of diving up to 4,000 meters—about 2.5 miles. Matsumoto points out that ROVs such as these eliminate many of the drawbacks of occupied submersibles. "Remote vehicles are much, much more inexpensive to run," Matsumoto says. Human-occupied vehicles, Matsumoto says, are limited by battery power, oxygen levels and the capacity of human endurance, "while in an ROV there aren't really any limits. Doing a 12-hour dive is pretty standard for us."

To reach these deep waters, MBARI researchers don't need to go far. Less than 100 yards from their offices is the "entrance" to Monterey Canyon, a massive underwater abyss comparable in scale to the Grand Canyon, its walls sloping down more than two miles at its deepest point. This proximity allows MBARI to undertake missions as frequently as every day, and at a fraction of the cost of similar missions in other parts of the world. "Within an hour of leaving the dock, we can be in more than 1,000 meters of water," Matsumoto says.

Much of this massive underwater realm consists of what scientists call the ocean midwater. Beginning at the point where all but 1 percent of the surface's sunlight is filtered out—in Monterey Bay, this is around 300 feet down—and extending down to just above the ocean floor (in the Pacific, the median depth is around 13,000 feet), the midwater ecosystem is the largest environment on the planet, but due to its forbidding depths, it is also the least understood. Since MBARI's founding in 1987, though, scientists have sent ROVs on thousands of dives into the canyon, making Monterey Bay perhaps the most studied midwater environment on the planet.

Using ROVs, researchers have been able to study the previously unknown behaviors of cephalopods, such as octopuses and squids, as well as discover many new animals—mainly

COURTESY: MBARI

COURTESY: DAVID WELCH (LEFT); TOPP PROJECT TEAM

**Top: *Tiburonia granrojo*, or "Big Red," is a species of jelly recently discovered by MBARI researchers. Above left: Acoustic tags implanted on a small salmon will allow it to be tracked as part of the Census of Marine Life's Pacific Ocean Salmon Tracking (POST) project. Above right: Scientists tag a bluefin tuna as part of the Census' Tagging of Pacific Pelagics (TOPP) program. Below: An integral part of nearshore ecosystems, kelp is being surveyed as part of the NaGISA project, another Census pilot study.**

COURTESY: DR. BRENDA KONAR, UNIVERSITY OF ALASKA FAIRBANKS

fragile deepwater creatures such as jellies (the preferred term for "jellyfish"). "We've seen things in trawl nets before, but this is the first time we've actually seen them in their habitat," Meyer says. "Comb jellies, for example, are very delicate. The ability to see them in the water, and collect them without touching them, allows us to examine and classify a lot of these gelatinous animals. ROVs are tools that are particularly well-suited to finding new things."

Many of these animals would be unrecognizable if brought up in a trawl net. Siphonophores—an order of midwater jellies with more than 150 known species, including the Portuguese man-of-war—are significant predators in the midwater ecosystem, yet their fragility has prohibited gathering them in a net for study. Even *praya*—a gangly, tentacled siphonophore that can have as many as 800 stomachs and grow to 40 meters in length (making it the longest animal on the planet, though its body is only the width of your finger)—are destroyed when caught in a net, making the information gathered by an ROV all the more significant. Researchers are now realizing the astonishing diversity of the midwater ecosystem, and MBARI estimates that jellies may make up as much as 25 percent of Monterey Bay's biomass.

Matsumoto says MBARI researchers observe a new species once a month, on average. But actually identifying a new species is time-consuming; this was the case after a MBARI geologist spotted a very large and unusual jelly on the *Tiburon*'s cameras during a geology expedition in 1998. The first sighting of the jelly—originally called "the Gumdrop" after the Gumdrop Seamount (about 75 miles west of San Francisco), where it was first seen—was memorable: The robust jelly was a meter wide and colored deep red, with a few short, thick arms instead of the usual cluster of tentacles.

After several years of searching the scientific literature and combing through MBARI's extensive database, Matsumoto published his study of the new species, named *Tiburonia granrojo* after the ROV *Tiburon*, in the scientific journal *Marine Biology* this past May. "A lot of times, like with the big red jelly, we may see [a new species] but not realize it right away," Matsumoto says. Even now, much about the animal remains unknown. "We don't know what it eats, what eats it, or its full distribution," Matsumoto says. "We'd like to find out where it lives—does it live in the Atlantic, for instance? We don't know."

Each fragment of knowledge gathered by researchers contributes to learning more about the role these creatures play. "Jellies, or gelatinous zooplankton, are a much more important component of ocean ecosystems than anyone ever thought," Matsumoto says. Siphonophores, for example, eat copepods—small crustaceans that are also food for fish and whales—so a growth in the siphonophore population could have repercussions throughout the food chain, affecting sharks, whales and ultimately humans. Issues such as this only underscore the importance of continuing the research into jellies. "There are more of them, they're wider distributed, and they occur with greater frequency than anyone knew," Matsumoto says.

While technology is allowing glimpses of marine life never before seen, it is also revealing the secrets of much more familiar animals, whose behaviors and interactions are still little understood. The difficulty here, as with deep-sea creatures, is to overcome the ocean's obstacles, which prevent effective observation of its inhabitants.

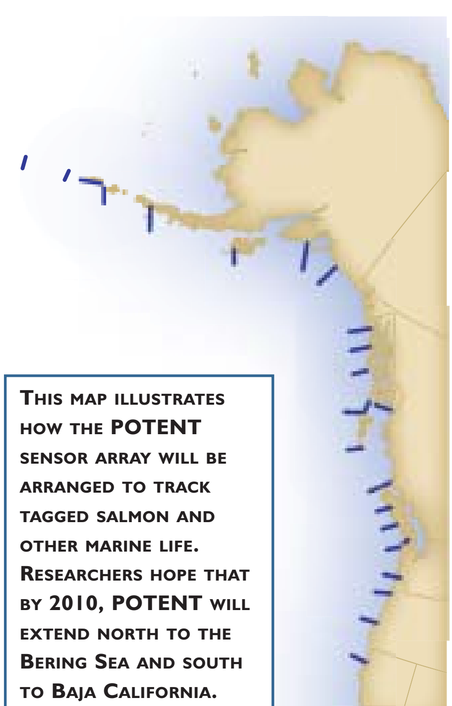
"If we were talking about African lions on the Serengeti, you'd have a whole set of images you could see," says Randy Kochevar, the science communications manager at the Monterey Bay Aquarium. Kochevar is standing in front of the aquarium's "Open Waters" exhibit, his face bathed in blue light as Pacific bluefin tuna and scalloped hammerhead sharks swim past just a few feet away. "If you wanted to see how the lions lived, you could get on a hill with binoculars and watch where they eat, where they sleep, and so on, and eventually you'd have a good idea of how that ecosystem works. We don't have anything like that for the ocean."

Thanks to improved satellite tracking technology, though, scientists are developing tools that can give them a better vantage. Kochevar is an outreach coordinator on a program called the Tagging of Pacific Pelagics (TOPP), part of a global, 10-year, estimated $1 billion research effort, the Census of Marine Life. A study unprecedented in scale, the Census brings together scientists from universities, institutions and government agencies from 40 nations in an effort to better understand the world's oceans and their inhabitants. Seven pilot projects are under way in select parts of the world, to study marine life forms ranging from blue whales to barnacles. These pilot programs will expand into longer-range studies over the next couple of years, and by 2010 Census researchers hope to have gained the insight into the world's oceans that has eluded scientists for so long. To accomplish this lofty goal, Census projects are using new technologies to gather information never before accessible.

For TOPP, this means learning more about the Pacific Ocean's large pelagics—a category of animals that ranges from humpback whales and elephant seals to albatross, tunas, sea turtles and great white sharks. Pelagic carnivores all share the characteristics of being high on the marine food chain, and being known to roam the open ocean. Some pelagics, such as bluefin and albacore tunas, are heavily exploited by commercial fisheries, yet scientists know little about how these animals live—where they travel, where they feed, and ultimately, how many of them there are.

"We're in the 21st century, and what we know about large pelagics in the Pacific Ocean is almost nothing," says Barbara Block, a marine scientist at Stanford University's Hopkins Marine Station and chief scientist for the TOPP project. "We want to know if there are common 'watering holes' where these tunas, sharks and whales come together." To accomplish this, TOPP is placing sophisticated tags on a whole suite of pelagic animals, with a goal of tagging 5,000 animals from 20 different species by 2008.

Tagging is not new—scientists have, for years, used simple tags to get snapshot glimpses of fish movement by comparing the point of a fish's release with the point of its recapture. Recently, though, Block and her co-workers pioneered the use of archival tags, computers surgically implanted into animals such as bluefin tuna, that collect large amounts of data on the animal's movements and the ocean conditions it encounters. The drawback with archival tags, though, is that the animal has to be caught in order to recover the data, so use of these tags has mainly been limited to fish such as tunas, which are targeted by commercial fisheries.



This map illustrates how the POTENT sensor array will be arranged to track tagged salmon and other marine life. Researchers hope that by 2010, POTENT will extend north to the Bering Sea and south to Baja California.

To increase the project's reach, TOPP scientists have also turned to tags that relay information to satellites. Pop-up tags, which are essentially small computers that gather data such as water temperature, light levels (which help determine the animals' location), and depth at two-minute intervals, are attached to the dorsal fin of an animal such as a great white shark via a thin, detachable lead. After a predetermined time period—say, six months—the lead disintegrates, and the tag detaches from the animal. The tag then floats to the surface, where it transmits its data to the ARGOS satellite.

Still, researchers may have to wait for months before a tag pops off and begins uploading. Another variety of tag used by TOPP researchers relays information directly to satellites while still attached to the animal. One type—the Smart Position and Temperature Transmission 2 tag (SPOT2)—allows researchers to track, in real time, pelagics that regularly spend time at the surface. When attached to the dorsal fin of an animal such as a salmon shark or sea turtle, the SPOT2 tag tracks data like the pop-up tag does, but relays that data automatically each time the animal surfaces and the tag is out of water.

Last July, Barbara Block and a team of researchers from Stanford, the Alaska Department of Fish and Game, and the National Marine Fisheries Service experimented with SPOT2 tags in the Gulf of Alaska. Venturing out of Cordova and into Prince William Sound, the team tagged 10 female salmon sharks. This species is unique in that it is the only shark known to frequent the cold Alaska waters, and even then, only females are seen this far north. The salmon shark is also unique in that it is warm-blooded, a characteristic that requires it to frequently rise to the warmer surface, but that also gives it tremendous muscle power. Of the 10 sharks tagged by Block's team, all transmitted data from their SPOT2 tags on at least a daily basis, and a year later, six are still transmitting, allowing a rare glimpse into the unknown world of the salmon shark.

"For the first time, we've tracked a shark through its full-year migration cycle," Block says. "We didn't know we'd be able to track the sharks for so long." The TOPP team discovered that the sharks fed in Alaskan waters for the summer (some remaining into early winter) before heading south. A few stopped to feed near salmon streams on Vancouver Island and in Washington state, and all eventually traveled to Mexico.

"We're integrating environmental information from satellites with the tagging data to learn why they go feed in the places they're going, and why they go breed in places," Block says. "We believe they're going down to Mexico to have their pups, and then come back. What we don't know is where the boys are."

These kinds of tags make a pelagic animal a sort of living oceanographic probe—capable of moving about naturally, while gathering data on an array of ocean conditions. The potential is immense. "This is the gathering of oceanic data on a scale never before possible," Kochevar says. "If we can tag a large enough number of animals, we'll have data that all the research vessels in the world couldn't get."

While these types of tags are useful for large animals, their size, function and cost are impractical for tracking smaller fish, such as salmon. Yet with the high economic value of salmon and the significant role they play in the ecosystem, scientists are also attempting to learn more about their movements and behavior. For Pacific salmon, much attention has been paid to inland waterway conditions—such as streamside development and the existence of hydroelectric dams—yet little is understood about what happens to these fish once they enter the ocean.

"We know Pacific salmon cover the entire ocean, all the way to Japan and as far down as California, but we don't understand how they get there or how they get back," says David Welch, a fisheries biologist in Nanaimo, British Columbia, and co-director of the Pacific Ocean Salmon Tracking (POST) project, another Census program. To solve this mystery, POST researchers have developed plans to tag Pacific salmon with small acoustic transmitters, each about the size of a pencil eraser. (Some fish will also be tagged with archival tags that will gather data on temperature, salinity and depth). By sending out a signal acoustically, the transmitter won't have to rely on an electronic signal (which can't travel through seawater), eliminating a major obstacle to previous tracking efforts. "Even a nuclear submarine can't send an electronic signal," Welch says. "The revolution in electronics that powered the cell phone systems is now being used in acoustic tracking equipment to allow us to do these sorts of things."

An array of undersea listening sensors, laid along the continental shelf, will detect and track each fish as it swims past. These sensors will be laid in an acoustic curtain that will, Welch hopes, cover the entire Pacific coast, from the Bering Sea to Baja California, by 2010. This curtain, called POTENT—for Pacific Ocean Tracking and Evaluation NeTwork—will eventually enable scientists to track the movements of many different types of fish and marine mammals.

To test the system, last summer Welch and his colleagues implanted acoustic tags on 120 wild steelhead smolts, and released the fish into the Waukwaas River, which flows into the Quatsino Sound fjord system on the west coast of Vancouver Island. To detect the fish, acoustic receivers were positioned in two long lines across Queen Charlotte and Johnstone Straits, on the east coast, and in six lines within Quatsino Sound on the west coast. Scientists were able to track all 120 smolts for two months as they made their way to the ocean.

Using the data from these studies, researchers hope to learn more about the movements of salmon (and, ultimately, other fish) and the oceanographic conditions they encounter. Plans are under way to establish acoustic arrays during the next two years in an area Welch calls the Salish Sea—a broad expanse of water that includes the Strait of Georgia, the Strait of Juan de Fuca, Puget Sound, Queen Charlotte Strait and several river estuaries in Washington and British Columbia. And researchers also hope to start tagging many types of fish and mammals at the same time, including lingcod, rockfish, sea lions and possibly orcas. By the time the coast-long array is in position at the end of the decade, scientists will have a system capable of tracking the movements of more than 250,000 individual animals at a time. "If we're successful with it, we'll have the equivalent of the Hubble space telescope in the ocean," Welch says.

While Hubble-scale technology is integral to Census projects such as TOPP and POST, a third pilot project relies on simpler, bucket-and-scraper methods to study the ocean's biodiversity. NaGISA—an acronym for Natural Geography In Shore Areas, but also a Japanese word for the narrow intertidal zone where land meets the sea—is a project to assess and quantify marine biodiversity in some of the most biologically diverse and productive areas on the planet. The focus of the project seems narrow: Only tide zones with rocky bottoms, kelp beds or seagrass beds are studied (sites such as coral reefs and sandy beaches are not), and only five one-meter-square areas from each of seven depth-levels (ranging from high tide to 15 meters underwater) at each research site are sampled. But NaGISA aims to observe and sample all types of marine life—including animals such as sea stars, mollusks, sponges and barnacles, as well as plants—within these areas. The results will be compiled in a comprehensive database called OBIS (for

Ocean Biogeographic Information System), along with results from other survey sites taken along globe-spanning transects, one running pole to pole, from Alaska's Beaufort Sea coastline all the way down to Antarctica's McMurdo Sound, and another that circles the globe at the equator. This broad approach allows NaGISA researchers to compare the diversity of one area to another, but by focusing on small areas that can be sampled by hand, it provides a way to include small, coastal communities, such as those found in Alaska, in the Census of Marine Life's ambitious programs.

"We typically don't need large research vessels, or ROVs, icebreakers or all that really expensive scientific gear," says Brenda Konar, a marine scientist at the University of Alaska, Fairbanks. Konar and her colleague at UAF, Katrin Iken, are coordinating NaGISA's latitudinal transect, and are currently planning or conducting pilot project studies in six Alaska coastal areas (NaGISA's longitudinal-transect study is being coordinated by the Seto Marine Biological Laboratory in Kyoto, Japan). The project entails the simple observation of 35 meter-square areas randomly selected along the tide zone—including shallow-water areas that can be accessed using scuba gear—and the collection and categorization of macroalgae, such as kelp, in 50-centimeter-square areas, and of all living things in smaller, 25-centimeter-square areas. Konar says this kind of focused, low-tech method is particularly well-suited to involving local people in the sampling effort. "It's easy to go to Kodiak, get the community out, and get the kids to help us do the intertidal sampling," Konar says.

What sets NaGISA apart from other, similar field studies is its use of a standardized sampling protocol at all sites worldwide. This allows the results to be entered into the OBIS database, monitored over time, and compared to the results found in other parts of the world. And while much of NaGISA's research covers marine life such as anemones and seaweed—things that arguably lack the charisma of, say, an otter or a dolphin—Konar says the sampling completed thus far, in Prince William Sound, Kachemak Bay and Kodiak, has sparked unexpected interest from her students and local helpers. "One of my students at the beginning was complaining that he didn't want to learn all this about algae," such as different kinds of kelp. "Then, after about two weeks, he could pick one up and say, 'Hey, that's *Laminaria saccharina*, you can tell by the edges,'" Konar says. "And I said, 'Awww...,' " she laughs. "It's really great to see all these people getting excited about algae."

The data revealed by NaGISA's projects has real-life implications, as well. Inshore areas such as those covered by the study are some of the most biologically productive and sensitive places on Earth, and understanding their components can be key in times of need. "Now that we have baseline data on these sites, if there's a major catastrophe like the Exxon *Valdez*, we'll know what was there before," Konar says. "And if we keep sampling, we can see long-term trends, like global warming. Without this standardized base, this could never happen."

This long-term assessment is common to all the Census projects, and much of what is learned can be applied to the conservation of marine life. Coho salmon, for example, have seen a dramatic rise in at-sea mortality rates in the past few decades. "Whereas we might have gotten 10 adults back per spawner in the past, we now only get one," Welch says. "That has a huge impact. What we need to understand is where those young salmon go in the ocean, and what conditions they encounter there that explain the difference in survival."

The ability to see where marine animals go can be essential to crafting efforts to preserve fish, marine mammal and seabird stocks for generations to come. Ultimately, the information gained from these in-depth projects will help scientists understand which areas of the ocean are more sensitive or essential, and this knowledge will be of great assistance to governments and decision-makers. By the end of this ambitious project, "we believe we'll have a road map for the management of the living resources of the Pacific Ocean," says Barbara Block. "If we know the regions where animals use the ocean, we'll be able to understand the effects of human activity there."

*Paul Clarke is assistant editor.*