Listening in on the deep sea

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Ecologist Erin Oleson's research area spans 1.8 million square miles of sea. In this vast space in the Pacific Ocean, she must somehow track over 25 species of whales and dolphins. When Oleson started her work 8 years ago, she felt overwhelmed and thought, "How can we ever possibly understand what is out here? It's such a huge space … This just seems like a daunting task."

Oleson, who heads up the Cetacean Research Program at the National Oceanic and Atmospheric Administration's (NOAA's) Pacific Islands Fisheries Science Center in Pearl Harbor, says her task is further complicated by the elusive nature of many cetaceans. Take beaked whales, for example. At least 10 species in this deep-diving group live in the North Pacific. Because these whales surface so infrequently, researchers rarely spot them and hence have limited information about their distribution and prevalence.

Now, the rapidly developing field of passive acoustic monitoring is helping scientists like Oleson hear the animals they often cannot see. By tethering underwater microphones to the ocean floor, boats, or even the animals themselves, researchers are gaining new insights into marine mammal ecology, distributions, and behaviors. Such findings are critical for conservation: scientists can't protect cetaceans if they don't know they're there. And they can't address species declines without baseline estimates for healthy populations.

An Emerging Field

Marine scientists often survey whale and dolphin populations visually from boats. With powerful binoculars, researchers scan the ocean for wildlife as the boat moves along a sampling transect. In clear weather, they can spot a whale on the horizon.

But a single boat can only capture a small swath of space and time. "People don't understand how undersampled the ocean is. It's very spotty," says Oleson's former graduate advisor, John Hildebrand of the Scripps Institution of Oceanography. "If you put an acoustic sensor out, you get a continuous record. That's a pretty powerful thing." Marine passive

Marine scientists use underwater sound recording devices to track the distribution and prevalence of cetaceans like the Blainville's beaked whale, shown here. Image courtesy of Flickr/National Oceanic and Atmospheric Administration.

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NOAA scientists are developing underwater vehicles, known as gliders, that can record sound and then transmit it back to researchers via satellite. The glider shown here has three microphones, each capable of capturing different frequencies of marine sounds. Image courtesy of Ethan Roth (University of Hawaii at Manoa, Honolulu).

acoustic monitoring methods record the sounds the animals produce over days, months, or even years. The approach is cheaper and less disruptive than visually sampling by boat, and remains effective at night and during bad weather.

Scientists have experimented with marine acoustic recordings since the 1950s, when William Watkins and William Schevill of the Woods Hole Oceanographic Institution first tuned the world in to whale and dolphin sounds (1). Back then, the researchers had to actually see a marine mammal to make recordings, dipping underwater microphones, called hydrophones, a few meters into the water. It wasn't until the 1990s that biologists started experimenting with autonomous recording devices that could be left out at sea (2).

Today, researchers have recording devices, data storage, and sound-processing capabilities that allow them to study months' or even years' worth of underwater sounds across a broad range of frequencies, from the complex song of the humpback whale, which typically spans from about 50 Hz to 400 Hz, to the click of a dwarf sperm whale that is too high for the human ear to register.

Such techniques have helped clarify the distribution of those elusive beaked whales. Oleson and colleagues from the Scripps Institution of Oceanography placed underwater sound recording devices at 24 sites across the North Pacific (3). Between 2005 and 2012, the team recorded ∼11 years of ocean sound across these sites, generating insights into the specific sounds the species make and the locations they frequent. The researchers now know, for example, that beaked whales are nearly always heard near Kingman Reef in the Northern Line Islands, but rarely heard at another site in the Gulf of Mexico.

Seeing with Sound

Oleson and her NOAA team continue to maintain six of the autonomous passive acoustic data recorders. Tethered to the ocean floor, each floating recorder is suspended hundreds of meters underwater. The team has recorded sound at each of these sites for 5 or more years. At least once a year, they visit them to retrieve data.

The NOAA team also tows underwater microphones, known as hydrophone arrays, off the backs of ships to collect data on marine mammals across a broad range of ocean. And they and others are developing underwater vehicles, known as gliders, which can be programmed to dive hundreds of meters down, collect sound and other oceanographic measurements, and then return to the surface and transmit data back to researchers via satellite. Marine ecologist Mark Baumgartner at the Woods Hole Oceanographic Institution is already using one version of these gliders to collect data on marine species' presence.

Oleson now has nearly 200 terabytes of data from her six autonomous recording sites alone, which she has just started to sift through. "It's so much data that we will forever be asking questions of it, even if we stopped now and never collected another piece," says Oleson. "There's a lot of detail about more than 20 species of cetaceans, and human-caused noise, and fish."

Developing software that pulls meaningful information out of massive amounts of sound data is an active area of research, says oceanographer Bob Dziak, who directs the Acoustics Program at NOAA's Pacific Marine Environmental Laboratory. Dziak emphasizes the need for computer programs that can "analyze the data, detect signals, and facilitate rapid evaluation."

Some species, such as blue whales and fin whales, make consistent enough sounds that today's software can recognize them. But for most species, Oleson's team must process recordings manually. They first convert the data into spectrograms: graphs that show changes in sound frequency and volume over time. A single spectrogram might cover an hour of recording. Then, if they see sound registered on the graph in the right frequency range for cetaceans, the researchers zoom in to finer time scales to see, for example, the visual structure of the click of a beaked whale.

Filling the Gaps

With passive acoustic monitoring, Oleson and others are developing a rich picture of cetacean life. Using 3 months of sound recordings and environmental data from a remote seamount in the equatorial Pacific, Oleson found that beaked whale species use the habitat nearly every day (3). But, as it turns out, the species take turns. One beaked whale species was often present when sea-surface temperatures were high and sea salinity was low, whereas another showed the opposite pattern. Oleson says this finding illustrates how ocean habitats are constantly changing and individual beaked whale species respond by moving toward their preferred environmental conditions.

Marine biologist Susan Parks at Syracuse University and her team tracked animal movements by using suction cups to temporarily attach passive acoustic monitors to 14 North Atlantic right whales, a critically endangered species. Doing so allowed the team to identify the calls made by individual whales; and because the calls were unique, statistics software enabled the researchers to distinguish individuals and age classes (4). Ultimately, Parks would like to be able to pick out individual whales in recordings from stationary acoustic monitors and better estimate their prevalence.

Already, as part of a real-time conservation application, acoustic monitors attached to buoys help prevent ships from striking right whales in the main shipping lanes into the Massachusetts Bay and Boston Harbor (5). The monitors collect data on right whale calls, which is then sent to researchers via cellular or satellite phone. The researchers then warn ship operators, who can slow or divert ships to avoid hitting the whales.

Twenty Animals or 2,000?

Even with new technologies, the data have limitations. There are many sounds that researchers still have not been able to match to species. And even for those they have, the sounds alone typically cannot tell researchers how many animals are present. "If a lot of dolphins swim by, and you're listening to this cacophony of dolphin sound, it's really hard to tell, is that 20 dolphins or is that 2,000?" says Oleson.

Because understanding the abundance of marine mammal populations is critical for conservation efforts, scientists are working to develop models that generate population estimates while accounting for these limitations. "Ultimately, you want to make it quantitative enough to say, 'I recorded *x* number of sounds in this location. Therefore, the density in this location is *y*,'" explains Hildebrand.

"It's hard to count the number of calls and know how many whales are there unless you know how often they call," says Parks. "We try to figure out the range of call rates. Does it vary by age and sex? Does it depend on what habitat they're in? ... It's difficult to get enough samples from endangered species."

Oleson is working to overcome some of these challenges by pairing acoustics with satellite tags. When a tagged animal swims by an acoustic recorder and makes a sound, the team links sound with species. They also pair visual counts of marine mammals with acoustic recordings made from the same boat. "That can tell us that the smear of acoustic energy that just swam by was 200 spotted dolphins," says Oleson. "Over time, you can develop a relationship between the numbers the visual team is observing and some characteristic of the acoustics."

Oleson no longer feels daunted by her responsibility. "I started feeling like, 'Hey, we just monitored this space for a year with this acoustic recorder. Look at all of the things we're going to learn.'" she says. "You can't just keep feeling overwhelmed. You've got to find a solution."

1 Schevill W, Watkins W (1962) Whale and porpoise voices: A phonographic record. *Woods Hole Open Access Server*. Available at darchive.mblwhoilibrary.org/handle/1912/7431. Accessed March 27, 2017.

2 Baumann-Pickering S, et al. (2014) Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. *PLoS One* 9:e86072.

3 Baumann-Pickering S, Trickey JS, Wiggins SM, Oleson EM (2016) Odontocete occurrence in relation to changes in oceanography at a remote equatorial Pacific seamount. *Mar Mamm Sci* 32:805–825.

4 McCordic JA, Root-Gutteridge H, Cusano DA, Denes SL, Parks SE (2016) Calls of North Atlantic right whales *Eubalaena glacialis* contain information on individual identity and age class. *Endanger Species Res* 30:157–169.

5 Woods Hole Oceanographic Institution (2008) New whale detection buoys will help ships take the right way through marine habitat. Available at www.whoi.edu/page.do?pid=7545&tid=3622&cid=40629. Accessed March 27, 2017.