PART 2

What happens underwater?

By Polly Shulman

How Have Scientists Studied Blue Whales in the Past?

Humans have been fascinated by whales for thousands of years; these giants of the deep swim through our myths and some of our oldest writings. But studying them is difficult for some of the same reasons that make them so fascinating: their overwhelming size, and the great depths at which they spend so much of their time. Blue whales, especially, are too big to capture and keep alive for observation. They were too big to hunt from the wooden boats our seagoing forebears used to chase smaller whales, and they dive deeper than human divers can follow.

Until recently, therefore, everything scientists knew about blue whales they learned by using tools and techniques from the 20th century and earlier, but they were limited to what they could observe on land or just beneath the water. They could examine the bodies of whales that washed up on shore (**Fig. 1**). Later, when advances in shipbuilding techniques allowed whaling, they could study animals killed by hunters, performing anatomical studies and analyzing the contents of their stomachs.

Figure 1. Beached whale. Until recently, everything we knew about whales was limited to what we could learn by studying them on shore or just beneath the surface. Photo © Danny Frank/AGE Fotostock

From surface observations, scientists know that blue whales typically dive for about 10 to 20 minutes when they're feeding, although when they are less active they can hold their breath for 30 minutes or longer. (When scientists talk about a whale's **dive**, they mean not just the trip downward but the entire process of moving deeper into the water, performing underwater activities, and returning to the surface to breathe.) But whales spend most of their time beneath the waves—sometimes far beneath. So what does a blue whale do underwater?

The Scientists

A group of marine biologists at Stanford University's Hopkins Marine Station in Pacific Grove, California—including principal investigator Jeremy Goldbogen, postdoc David Cade, and graduate student Shirel Kahane-Rapport—have revolutionized the study of whale behavior by developing multisensor **tags** and attaching them to whales. Since they began deploying the tags, in 2014, they've attached almost 300 to whales belonging to six species throughout the world's oceans, many of them in the researchers' local waters of Monterey Bay. The tags gather many kinds of data about what the whales are up to underwater.

The biologists aim to understand how these marine giants evolved and live, but they also hope that their research can aid in conservation efforts, informing scientists and regulators as they develop fishing regulations, map shipping routes, and create protected areas. The more scientists and regulators know about the whales' behavior—such as where and how they feed, migrate, communicate, mate, give birth, and feed their young—the better able they will be to help shape conservation strategies.

Data collection is an extreme sport. "The first couple of times you tag a blue whale," says Goldbogen, "your legs are shaking and you're trying to just focus and make sure you get that tag in just the right spot, but it's an absolutely amazing experience."

The researchers go out on a small boat, affix sensor-laden tags to long poles, hang off the edge of the boat, pull up alongside a whale during the few seconds when it surfaces to breathe, and attach the tags via suction cup to the giant (**Fig. 2**). "It's a lot of adrenaline," says Cade. "You're trying to get this small device on a large whale. You have a 20-foot pole, and you have a four-second window in which to get the boat close enough to put the tag on the animal and then get out of the way. It takes a lot of coordination and teamwork." Compounding the risk to life and limb is the risk to the team's budget if a tag gets lost or destroyed. "You know you're doing oceanography when [the equipment] is too expensive to throw in the ocean but you do it anyway," says Cade, laughing.

Figure 2. Tagging a whale. Marine biologists on Goldbogen's team place a tag on a whale as it breaches the water's surface. Photo © AMNH

The team uses different types of tags depending on the research questions they're investigating. To learn about long-term behavior such as migrations, they need tags that will stay put for weeks or months. For that they use "very small darts that can embed the tags in the blubber," says Goldbogen, but those long-term tags have limited capacity for collecting data. To investigate questions about intricate behaviors that take place over a shorter period, such as feeding and acrobatic movements, they need much more detailed, fine-scale data. Collecting all that data requires more sensors and bulkier casings. The scientists don't want to burden the whales with that much weight for months at a time, so they use tags that attach with suction cups (**Fig. 3**). Although these tags don't stay put for very long (typically around one day), they have the advantage of being completely harmless to the whale.

Once suctioned to a whale, the tag records how fast and deep the whale dives, how it moves through space, and even the sound of water rushing past an animal on the move. Front- and back-facing cameras take video of the surroundings. After a few hours, or sometimes a day or two, the suction fails "like on your bathroom mirror, when everything comes crashing down," says Cade. Even if the suction is still going strong, the patch of skin it's stuck to may not be. Whales have permeable layers of skin that they shed naturally, exfoliating the tag along with the skin.

Once the tag falls off, it floats to the surface and emits a radio signal that's tracked by the researchers so they can scoop up the sensor and upload the data to a computer for analysis. Tags can be used again and again, as long as they're not lost at sea.

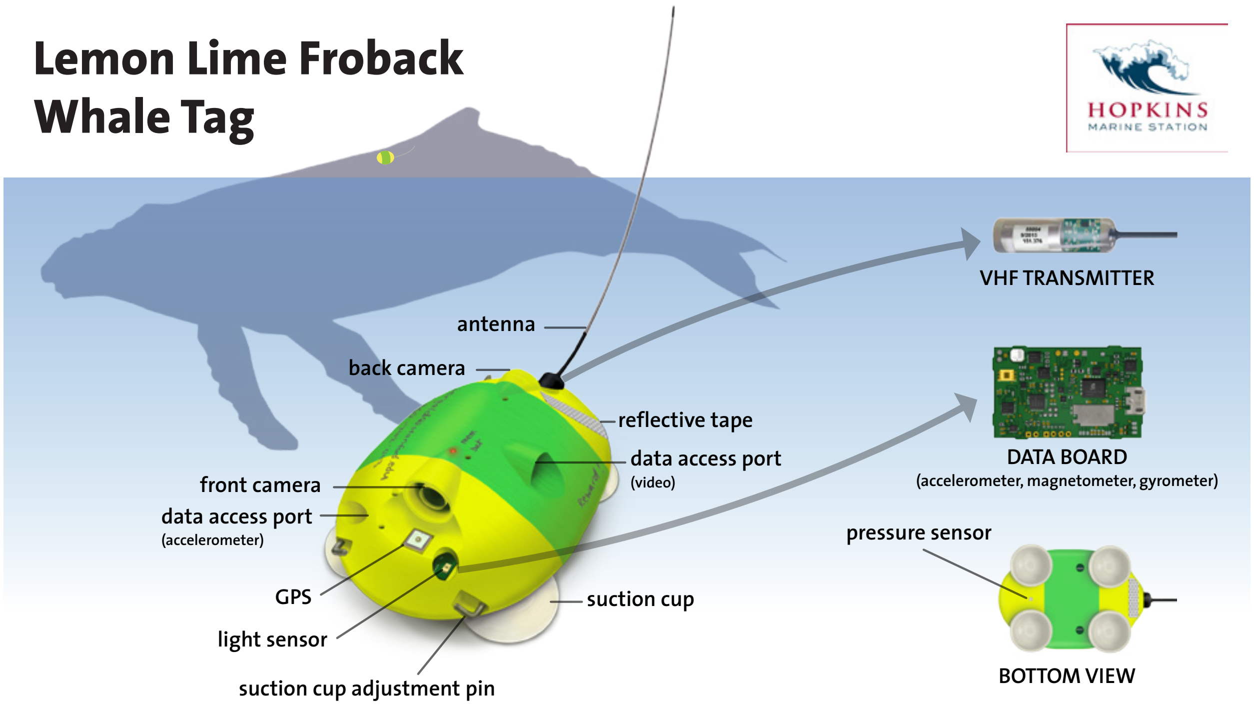

Figure 3. Whale tag with suction-cup attachment. Illustration by Alex Boersma

The Technology

Modern marine animal tagging began in 1963–64, when researchers integrated a pressure sensor with an ordinary 60-minute kitchen timer and strapped the whole thing to Weddell seals in Antarctica to collect data about the depth and timing of their dive. The scientists started with a disk of smoked glass: glass covered with a thin layer of carbon deposited from smoke. (If you've ever burned a candle inside a tall glass and noticed black streaks on the glass, you've seen this process.) Ticking through its hour, the timer rotated the disk; as the disk turned, a flexible needle attached to the pressure indicator arm on a Bourdon tube—a device for measuring pressure—scratched out a record into the carbon layer. The greater the pressure, the deeper the seal had dived.

Today's tags, which no longer rely on kitchen timers and smoked glass, have a variety of sensors that collect data at much higher resolutions than before. "For example," says Goldbogen, "the whale's movement is measured at several hundred times a second, and the acoustic information is sampled even faster. That gives us a really rich context for how the animal's moving and what's going on in the animal's environment."

Tag sensors include:

- **Accelerometer**, which measures forces of acceleration, including gravity. (Acceleration is the rate at which an object's velocity changes.) This sensor works with the magnetometer (see next bullet point) to provide information about an object's orientation in space. Like the accelerometer in a cell phone that senses whether you're holding the phone in picture or landscape orientation, the tag's accelerometer uses gravity to detect the whale's pitch: which way the animal is facing in the vertical plane, whether up, down, or somewhere in between.

- **Magnetometer**, which measures the pull of magnetism. Like a compass, this instrument detects the whale's heading: which direction it's facing in the north-south/east-west plane.

- **Sound recorder**, which uses hydrophones—underwater microphones—to sense the sounds in the whale's environment, such as its vocalizations, the sounds of its movement through the water, and the noises of other animals, including those produced by people and people's machines.

- **Video recorder** (with front- and back-facing cameras), which allows researchers to see the light in the whale's environment, as well as what that light illuminates. This is especially helpful for observing the whale's interactions with other organisms, including its prey, and how the whale is moving its body parts. For example, the front-facing camera allows the scientists to see when the whale opens its mouth to take a gulp, and the back-facing camera allows them to watch its tail movements.

- **Light sensors**, which measure the amount of ambient light.

- **VHF transmitter**, which sends out very high frequency (VHF) radio waves to alert the researchers so they can recover the tag once it has floated to the surface.

- **GPS (global positioning system)**, which works only in two- to three-second snatches as the whale breaks the surface. This may or may not be long enough for the tag to communicate with satellites and assess the tag's position.

- **Pressure sensor**, which measures water pressure, a proxy for depth.

- **Clocks on multiple instruments**, which allow the researchers to coordinate the data to understand the order of events. Although there's no single dedicated clock on the tags, clocks are integrated into the other sensors, such as the video and sound recorders. Synchronizing these timekeepers is challenging but important; discrepancies of even a few milliseconds can make a difference.

The scientists have used the data gathered by the tags to create many different visualizations for analysis. Among other graphs, they created dive profiles of the whales: more-detailed versions of the Weddell seals' dive profiles from the long-ago days of kitchen timers and smoked glass. The researchers plotted a whale's depth on the y-axis against the time of the dive on the x-axis (**Fig. 4**). As you look at the dive profile, remember that the only spatial dimension being shown is depth; this is a dive profile, not a map of the whale's path through the water. It's easy to misread the x-axis as distance, but in fact it's time.)

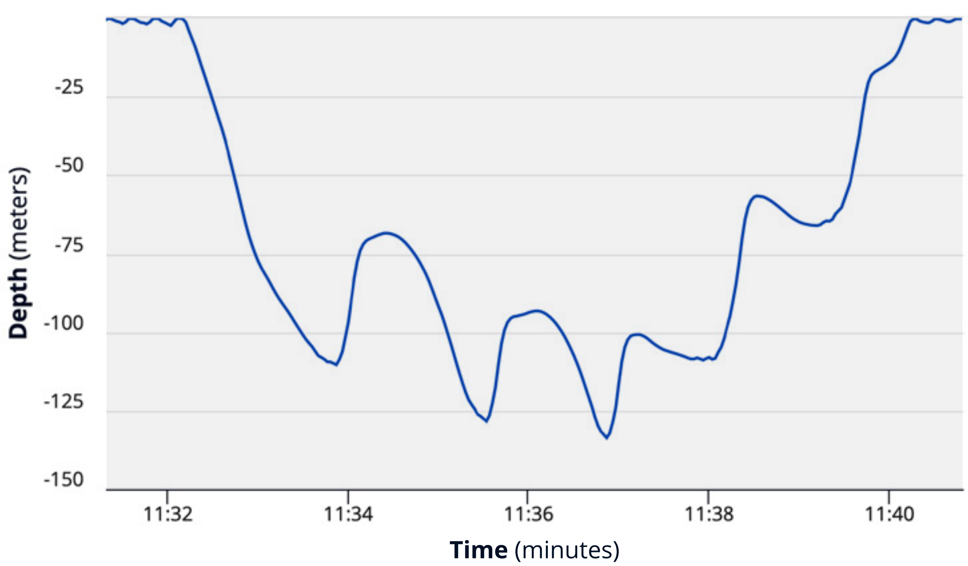

Figure 4. One whale's dive. This simple graph shows depth (y-axis) against time (x-axis) for a single dive—in this case, a whale with the identification code CRC-1009, a female that was first identified in 1994, making her at least 22 years old at the time the data were collected, and likely older.