

Researchers use a long pole to attach a digital tag, or D-tag, with suction cups to a whale off the Bahamas. The noninvasive tags record the movements of marine mammals and the sounds they make and hear under water. The tags (below) don't disturb the animals, giving scientists the ability to observe animals' normal behavior and see how they respond to sonar.



Investigating sonar and whale strandings

Navy opens undersea test site to scientists to find ways to avoid harm to marine mammals

Nine years ago, several U.S. Navy destroyers used sonar in the Bahamas during routine training exercises. Within 36 hours, 17 animals—including 14 beaked whales, one of the world's deepest-diving whale species—were found on three islands nearby.

Ten of the animals eventually refloated or were pushed back into the water, their fates unknown. The remaining seven died on the beach. Researchers examined the whales and found that they had died of heatstroke.

Speculation arose that the sonar had somehow disrupted the whales' behavior and caused them to swim to shore. Some of the whales also had hemorrhages near their ears and in the fluid surrounding their brains, which may have affected their hearing.

The unusual mass stranding, one of the few on record involving beaked whales, drew attacks on the Navy from environ-

mental groups and attracted interest from biologists, including Peter Tyack at Woods Hole Oceanographic Institution (WHOI). At the time, little was known about beaked whales, elusive species named for their beaked skulls. But Tyack knew it wasn't the first stranding of its kind. Five similar



strandings of beaked whales had coincided with naval exercises near Greece and the Canary Islands.

“One or two beaked whales stranding isn't unusual, but when we see larger numbers of whales stranding within a few hours over tens of miles of coastline, we know that there is something weird going on,” Tyack said. These atypical mass strandings were first reported by Alexandros Frantzis, a biologist at the University of Athens, in March 1998 in the journal *Nature*.

Blind without sound

Though sonar is vital to its operations, the U.S. Navy has acknowledged the problem it can pose to some whales. To learn more about sonar's impact on beaked whales, the Navy in 2007 opened the doors for researchers to use its extensive Atlantic Undersea Test and Evaluation Center—an

Bahamas Marine Mammal Research Organization

interconnected seafloor network of 93 hydrophones (underwater microphones) arranged in a grid over 600 square nautical miles east of Andros Island, not far from the area where strandings occurred in 2000. The three-year research effort includes \$6 million in funding from the U.S. Department of Defense and the U.S. Navy.

"We recognize that one of our tools in use for 50 years may have detrimental effects on marine mammals under certain conditions," said Donald Schregardus, a deputy assistant secretary of the Navy. "We want to understand these effects better."

Schregardus said that results uncovered through the study, which continued last fall, would allow scientists to begin understanding how beaked whales react to human-produced sounds. It could also be used by the Navy to modify existing protective measures, develop thresholds for sonar, or perhaps explore modifying the sonar signal itself.

Nevertheless, sonar remains one of the Navy's most essential tools. "Sonar is the Navy's eyes beneath the water," Schregardus said. "Enemy submarines used to be easier to detect, as they used to be noisier pieces of equipment. Technology developments have changed them, making them harder to detect with acoustic devices."

"In many parts of the world, we simply can't move our ships without first being cer-

tain that something isn't in the water that may harm the U.S. and our naval forces," he said. "When you have 5,000 people on an aircraft carrier, you have to be certain the water is clear."

The Navy's ongoing use of sonar for anti-submarine warfare training along U.S. coasts has drawn a series of lawsuits from opponents, which culminated in a U.S. Supreme Court decision last November allowing the Navy to continue using sonar in training exercises (see article on Page 42).

Are beaked whales 'nervous Nellies'?

Darlene Ketten, a biologist at WHOI, examined the dead stranded whales in the Bahamas in 2000. She said it is important to remember that what killed the animals wasn't a blast from sonar itself. They died from injuries suffered as a result of stranding.

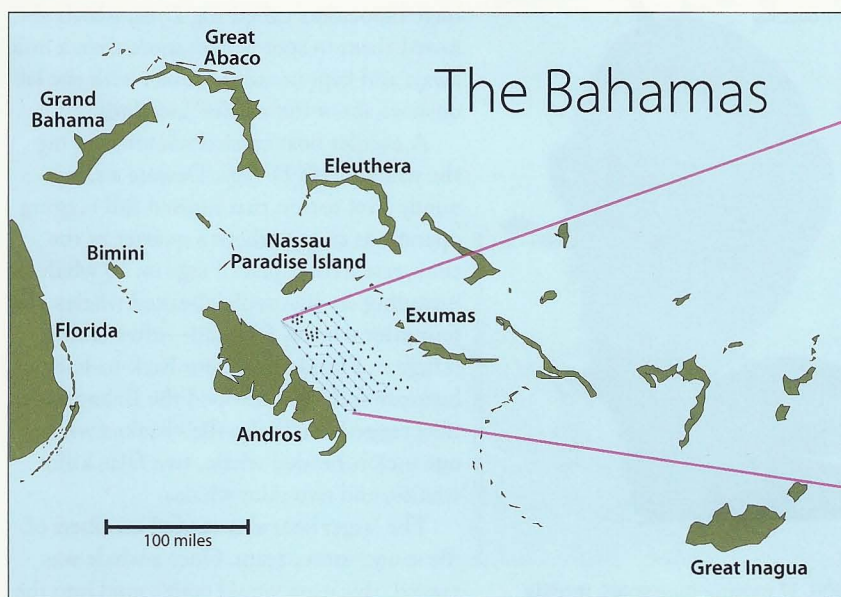
"There's no question that they died because a stranding occurred when naval exercises took place," she said. "But it is incorrect to say that all use of sonar by the military kills whales. We have no evidence that sonar per se is killing whales. Sonar is in use worldwide, by commercial and fishing vessels, as well as by the U.S. Navy and military ships from other countries. We just don't see hundreds and thousands of whales dying on beaches from injuries we can attribute to sonar."

Another critical question is why the beaked whale mass strandings seem to have occurred in several specific places. And Tyack said there are no reports of atypical mass strandings of beaked whales along the West Coast and Hawaii, though there have been several strandings in Alaskan waters.

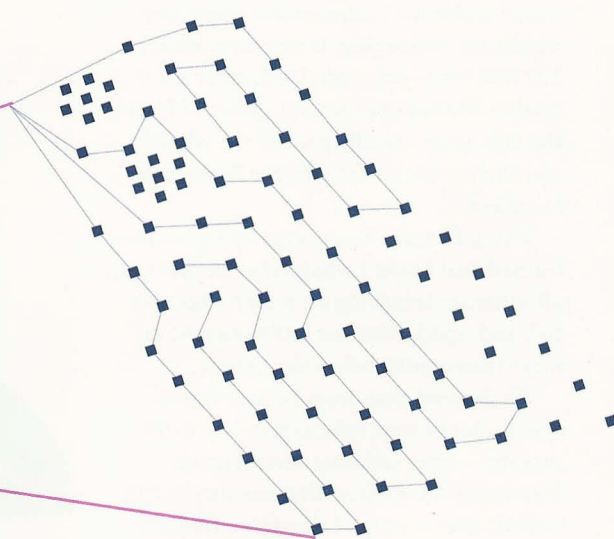
Each stranding location near Europe and the Bahamas had characteristics in common, said biologist Brandon Southall, a principal investigator on the Bahamas research project who directs the National Oceanic and Atmospheric Administration's Ocean Acoustics Program. All the strandings occurred only in tropical and subtropical areas with steep cliffs on the seafloor. Each shared similarities in how the water temperature varied with depth, which can cause sound to travel greater distances near the surface than it might otherwise.

"This provides some information about what set of circumstances would need to be avoided when using sonar, but we don't have a real road map yet," he said.

Reports of how the whales were injured as a result of stranding after exposure to sonar seem to vary. In the Canary Islands—but not the Bahamas—researchers reported that some stranded beaked whales had gas bubbles in their organs and veins. Researchers theorized that the animals may have suffered decompression sickness, or "the bends,"



Courtesy of the Naval Undersea Warfare Center Marine Mammal Monitoring on Naval Ranges Program



To explore links between sonar and marine mammal strandings, the U.S. Navy has offered scientists the use of its extensive Atlantic Undersea Test and Evaluation Center, which includes an interconnected seafloor system of 93 hydrophones (underwater microphones) arranged in a grid over 600 square nautical miles off Andros Island in the Bahamas.

Bahamas Marine Mammal Research.org/janiza.w

which sometimes afflicts scuba divers.

It was a curious symptom for whales, whose lungs are thought to collapse early in their dives to prevent nitrogen bubbles from infiltrating their bloodstream and causing decompression sickness.

Also puzzling is why sonar seems to affect specifically beaked whales, Ketten said. Although many marine mammals were in the area, beaked whales were the most common species to strand and die. Their particular physiology may be a factor, she said. Compared with other species, “they may be ‘nervous Nellies,’” she said.

Clues to a whale mystery

When Tyack first learned of the sonar-related strandings, he and WHOI engineer Mark Johnson were developing a noninvasive tag at WHOI to digitally record underwater sounds and the movements of marine mammals. The cell phone-size devices, called D-tags, attach to whales with suction cups and stay on during a dive. The tags don’t disturb the animal, which is critical for scientists seeking to observe and record normal behavior.

D-tags give scientists a picture of the animals’ movements and environment deep beneath the surface. The tags record the whales’ pitch, roll, speed, depth, and direction as they swim. They also record the sounds whales make, other sounds under water; and water temperatures where the whales are swimming. It measures sound 192,000 times per second and other information 50 times per second. After 18 hours, the tags automatically pop off the whales and float to the surface for the researchers to collect.

Using D-tags, Tyack and colleagues have learned that beaked whales dive deeper than all other air-breathing animals to hunt for fish and squid, roaming 2,000 meters, or more than a mile, below the surface.

To descend that deep, beaked whales spend a lot of time submerged—up to 90 minutes—after catching several quick breaths on the surface. Because they spend so little time on top of the water, they are notoriously challenging to study; Johnson described them as the “extreme breath-hold champions of all animals studied so far.” By comparison, a sperm whale may remain on the surface breathing for 10 minutes, giving

researchers ample time to attach tags before the whales submerge again.

The researchers unveiled a theory about why the deep-diving whales, in response to sonar testing, may sometimes succumb to decompression sickness. Tyack and Walter Zimmer of the NATO Undersea Research Center suggested that some naval sonars may replicate the sounds made by one of the whales’ predators, killer whales, and stimulate the whales to dive repeatedly just shallower than the depth at which their lungs collapse. The increased pressure from this risky diving pattern can cause nitrogen bubbles to form in some tissues, the scientists concluded in a paper published in 2007 in the journal *Marine Mammal Science*. Limiting the duration of sonar testing may reduce this risk.

A high-tech window into the deep

In August 2007, 60 scientists from 10 institutions gathered to launch the first season of a multiyear research project at the Navy’s testing facility in the Bahamas. The facility is known for its tropical temperatures (ideal for year-round work at sea), access to deep



In March 2000, 17 marine mammals, mostly beaked whales like this one, were found stranded on three islands in the North Bahamas after naval exercises involving sonar.

water (good for testing weapons and for finding deep-diving whales), and low commercial vessel traffic. All these factors provide an ideal backdrop for military work.

For scientists, the jewel of the facility is the seafloor hydrophone system. Researchers on land can see the hydrophone grid on computer monitors and acoustically track whales swimming beneath the surface. To eavesdrop on the whales, engineers at the Naval Underwater Warfare Center in Newport, R.I., developed a program called M3R (Marine Mammal Monitoring on Navy Ranges), which allows the hydrophones to pick up the sound frequency of the “clicks” that beaked whales use to echolocate. The frequency is too high for humans to hear.

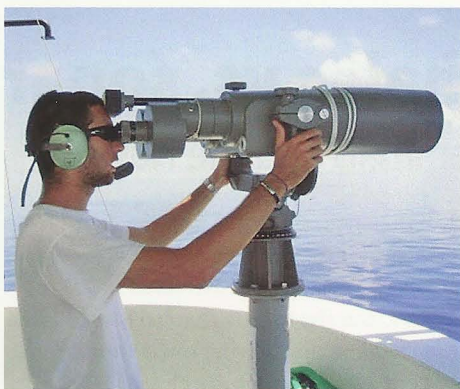
Early each morning, in the base’s on-shore acoustics room, researchers began by identifying where whales were located within the hydrophone array. The rectangular-shaped array, broadcast on computer monitors, showed colored lights representing each hydrophone. A green light meant no whale was nearby. But when it flashed red, the hydrophone was picking up something other than ambient sounds. The researchers could determine if the sounds were coming from a beaked whale, a sperm whale, or a boat passing through.

Once researchers had a general idea of whales’ locations, other teams headed out in boats. On one, researchers peered through huge binoculars called Big Eyes, which allowed them to spot whales more than a mile away, and kept in radio contact with the lab onshore about the whales’ locations.

A smaller boat carried scientists to tag the whales with D-tags. Despite a rainy, windy first season that limited full tagging operations to only about a quarter of the time, researchers placed tags on 10 whales, including six Blainville’s beaked whales and four pilot whales. Last fall—after taking refuge in Florida from four back-to-back hurricanes that sideswiped the Bahamas—they tagged one Blainville’s beaked whale, one melon-headed whale, two false killer whales, and two pilot whales.

The larger boat also carried members of the sound source team. Once a whale was tagged, this team would emit sound into the water, including sonar-like pings and calls from killer whales, so researchers could begin seeing how the beaked whales responded.

Man Hauser, The Center for Cetacean Research & Conservation



Whales were tagged using smaller boats, then tracked using the Navy vessel *Ranger*. Biologist Federico Pongiglione used the “Big Eye” binoculars on the bow of the *Ranger* to track beaked whales, even from a mile away.



Photos courtesy of Behavioral Response Study

Preliminary results show mixed reactions from whales exposed to sonar sounds.

When whales dive, they emit a series of high-frequency clicks, a form of echolocation that gives them a three-dimensional picture of their surroundings. “When the beaked whales we tagged were exposed to sonar, they quieted right up,” or stopped clicking, Tyack said.

One also reacted strongly to the piped-in call of an orca whale, a predator. “It surfaced slowly and left, basically swimming 20 kilometers in 10 hours,” he said.

However, pilot whales and false killer whales exposed to sonar signals would often increase their calling rate and form more cohesive groups, displaying little of the silence and avoidance behavior typically observed in beaked whales.

“There’s a lot left to interpret from this,” Tyack said. It could suggest that the whales that rely on social defense against predators are at less risk of stranding than species that might swim to shallow waters to flee predators, he said. “We’re slowly building up a library of samples. We’re getting good examples of who gets silent, who copies, and who moves away.”

Ari Shapiro, a biologist at WHOI, has begun analyzing data captured by D-tags. “We’re looking for patterns of behavior after sound is emitted in their environment,” he said. “We want to know, do the whales change course? Do they linger at depth or just take off? Maybe their vocalizations change.”

While research was under way in the Ba-

hamas this year, another team of researchers working off coastal Norway began a similar study of pilot whales, sperm whales, and orca whales—as well as herring feeding in the area, a popular food for whales and humans in Europe. Their initial studies found that herring reacted to orca sounds by fleeing or splitting up their schools, but showed no apparent reaction to sonar signals.

Tyack said he hopes for additional future research efforts worldwide, particularly in Taiwan and Japan, an area of the Pacific with many whales and a large military presence.

Whale safety precautions

Tyack described the research as a balance between not harming the subjects and obtaining critically needed information about how the whales react to sound. Researchers used a less intense sound source than the Navy sonar used when the whales stranded. They limited their work to the military range, where they could easily track where the whales moved and where they had been repeatedly exposed to sonar.

Tyack stressed that there is no intent to expose the animals to harmful sound sources that would cause them to strand. To ensure that, he said, researchers constantly watched for disruptions in the whales’ behavior. For example, beaked whales are known to begin clicking when they dive below 500 meters and continue clicking for 20 to 30 minutes. The researchers waited until whales started clicking at depth before they played back sounds, and they stopped transmitting as soon as they detected that

the whales had stopped clicking. Using this procedure, researchers can discern a minimum sound exposure necessary to observe a response.

“The point is to ramp up the intensity of the exposure over time,” Tyack said. Slowly, he said, they will get to a point where the whales show a measurable reaction to sound in the water.

Additionally, a plane flew over hundreds of miles of coastline after each playback to check for stranded whales in the region and made sweeps out to sea to look for “floaters,” or dead whales. They didn’t find any.

The research will continue next year. Scientists want to test sound on more beaked whales living in areas where they have likely had limited or no exposure to sonar. That way, researchers can learn from whales that aren’t already accustomed to hearing the signals.

—Amy E. Nevala

Funding for the Bahamas beaked whale behavioral study was provided by the Office of Naval Research (ONR), the Strategic Environmental Research & Development Program, and the Chief of Naval Operations Environmental Readiness and Submarine Warfare Division. The research was conducted under a Bahamian permit issued by the Department of Marine Resources, and under permit #1121-1900 issued by the National Marine Fisheries Service (NMFS) under the authority of the Marine Mammals Protection Act and the Environmental Protection Agency. Funding for the studies of stranded animals was provided by NMFS and ONR.