Acoustic Tracking of Fish: How Continuous Data on Fish Movement Could Change the Planning of MPAs

To design effective MPAs, planners need information on the habitats and species they want to protect. Data on the home range of a particular fish species, for example, can be invaluable for siting marine reserves to protect that species. Over the past several decades, scientists have tracked fish movement through mark-and-recapture techniques or following fish with scuba divers - generating useful, though incomplete, information. But technological advances in the past decade have enabled what could be a key to effective MPA design: continuous data on individual fish movements over time, including in and out of protected areas.

This tracking is enabled by acoustic telemetry - using battery-operated transmitters inserted into fish that collect and send data to receivers nearby. (“Acoustic” means the use of sound waves; “telemetry” means sending information from one place to another.) Although the technology has some limitations, including cost, it has been tested in several MPAs worldwide and yielded promising results. This month, MPA News examines the technology and the opportunities it offers to MPA planners and managers.

Window to the lives of underwater animals

Little is known about the home ranges of many fish species, or how the home ranges vary with age and season. This lack of information on movement and habitat preferences makes it difficult to determine effective MPA size and location. This is particularly the case for no-take marine reserves, where boundaries that are too small, or inappropriately placed, can result in inadequate protection for species of interest.

Traditional techniques for tracking fish movement have provided spoty data sets for researchers. Marking and releasing a fish, then recapturing it at a future date, yields two data points: where the fish was at initial capture and at recapture. All movement of the fish between those two points - potentially months or years apart - is lost. Other techniques such as offering fish with divers can influence the behavior of the fish under study, and yield relatively short-term data.

Underwater acoustic telemetry was devised to provide a cleaner and larger-scale view into the lives of marine animals. Developed in the 1970s but limited in marine use until recently by various factors, this technology is applied in two general ways. Researchers either manually track the movement of tagged fish from the water surface using hand-held hydrophones, or use networks of receivers attached to buoys to automatically monitor the data transmitted from the tags. The first method normally employs transmitters that emit a signal (a “ping” sound) every few seconds; this is great for real-time tracking of fish movement but results in a relatively short battery life (about one month) due to the frequent pinging. The latter method involves transmitters that ping less frequently, allowing for battery lives of up to a year or more.

To attach the transmitters to fish, researchers either surgically implant the devices (as small as 7 mm by 18 mm) in the abdomen after capturing and anesthetizing the animal, or feed the transmitter to the fish with food. Implantation is more difficult but tends to provide longer data series, as the feeding method results in eventual excretion of the transmitter. Each method places stress on the study animals, particularly deeper-water species whose swim bladders are not adapted to the pressures of surfacing (for the implantation process). However, researchers say that fish behavior stabilizes within hours to days after tagging. Ron O’Donnell, a biologist at Dalhousie University (Canada) who has experimented with acoustic telemetry since 1980, says the smaller the tag, the less effect it has. “Schooling fish have been observed to return to the same position in the social ‘pecking order’ after tag implantation, so it seems that even other fish cannot detect their behavior changes,” he says.

O’Donnell notes the advances that have allowed use of acoustic telemetry to become more feasible - namely the miniaturization of computer chips and lithium batteries, providing more power in smaller packages. “When I first started using acoustic tracking, the animals had to weigh half a kilogram [to be able to carry the acoustic devices],” he says. “Now animals as small as 10 grams can carry individually coded transmitters that last months to years depending on their transmission program.” The tags are also more rugged than they used to be, and have dropped in price. Smaller tags may now sell for US$300 or so - still pricey, but much cheaper than a decade ago. (The website for VEMCO, one of the largest manufacturers of acoustic telemetry equipment, shows the variety of transmitters and receivers now available: www.vemco.com.)

Results of acoustic telemetry research in MPAs

James Lindholm, a biologist at the Pfizer Institute of Environmental Research (US), has used acoustic telemetry to study Atlantic cod in the temperate Stellwagen Bank National Marine Sanctuary (SBMNS), off the northeastern coast of the US. With arrays of receivers, he monitored the movement of cod released over different seafloor habitats: gravel-covered bottom and piled boulder reefs. Although cod can be a relatively mobile species, Lindholm found that more than 1/3 (37%) of those released over gravel exhibited strong site fidelity: they were present within a 0.5-km² area for most of the four-month study period. Over piled boulder reefs, an even higher percentage, 50%, of the cod showed strong site fidelity. (In the latter case, the remaining 50% of fish were observed to move among the four boulder reefs in the study area, up to 24 km and three reefs in a single day.)

Lindholm says this variation in behavior, with some individuals of a species exhibiting strong site fidelity and others not, appears elsewhere in the global literature on acoustic tracking of fishes. “The mechanisms underlying this phenomenon will vary by species and are not well understood,” he says. He points out that Atlantic cod fishermen have long believed there are two types of cod - so-called “rock cod” that seem to stay put at particular features, and other cod that move more widely. “The fact that we have observed this behavior over both gravel and piled boulder reef habitats suggests there is clearly something going on here,” he says.

Despite the variability in behavior, the attractiveness of certain habitats to cod suggests that if managers were to designate no-take zones to protect the species, these habitats could be good candidates as sites, particularly for the individuals that exhibit site fidelity. SBMNS presently has no designated no-take reserves (aside from an overlap with a regional fishery management closure, in which Lindholm’s study took place), but a five-year management plan review process is underway and is considering various conservation measures. (National Marine Sanctuaries in the US are not required to have no-take areas, but can consider such restrictions if warranted.)

“Should the sanctuary consider designating some type of marine reserve or research closed area, I believe the data we have will assist in identifying the types of habitats that should receive protection, the particular locations for potential reserves, and the size of potential reserves,” says Lindholm. “If protection of cod becomes a priority, I think that discrete piled boulder reefs will be an obvious choice for protection.” Although cod trials in the region have historically avoided setting their gear on high-relief habitats like piled boulder reefs, recreational cod fishermen generally target these sites, returning to them regularly, says Lindholm.

Habitat preferences also play a role in tropical species behavior. In 1999, biologists Hazel Oxenford and Newton Enisthe of the University of the West Indies, Cave Hill (Barbados), used hand-held hydrophones to study acoustic tagged Bermuda chub in two reserves of the St. Lucia Marine Management Area (SMMMA), in the Caribbean nation of St. Lucia. Each reserve consisted of coral reef habitat: one bisected a relatively broad coral reef while the other encompassed a narrow, fringing one. The home ranges of the chub in each reserve reflected the reef shape, with circular home ranges observed in the first reserve and elongated home ranges in the second.

Movement of the commercially important chub across the reserve boundary into fished areas was recorded frequently in the case of the first reserve, namely to the contiguous reef outside the boundary. The second site, with no contiguous reef, had very little spillover. This was consistent with fish-count findings by other researchers, who had reported modest increases in fish biomass in the first reserve and...
much larger increases in the second. Although Oxenford says there are no plans to alter SMMA reserve boundaries for the time being, and that her study was not undertaken to inform such changes, "The research results could have broad application to other reserve areas where boundaries dissect rather than encompass whole habitats," she says.

Oxenford points out that using hand-held hydrophones to collect tag data, although more labor-intensive than using arrays of moored receivers, may be more practical in environments like St. Lucia, which has a narrow island shelf with strong surface currents. ePlacement of soro-buoys more than 100 m or so to seaward of the reefs would have to include deepwater moorings," she says. "Because of the currents, very strong flotation devices would be required on the moorings to prevent the soro-buoys from being dragged down horizontally onto the bottom."

In any case, the acoustic telemetry she used was a big improvement over mark-and-recapture studies, says Oxenford. "We were working in reserves with a recent history of public outcry, especially from reef fishers upset over reduced fishing area," she says. "Repeated capture of fish by researchers within the reserves would have been unacceptable at that time, and undoubtedly would have caused public outrage. Visual recapture would have been the only acceptable alternative. However, the number of diver-hours in the water would have had to have been very large to obtain the same volume of data as our study."

**Selecting for individuals with smaller home ranges?**

Darren Parsons, a biologist at the Leigh Marine Laboratory (New Zealand), used an array of receivers to study the home-range size and location of snapper (Pagrus auratus) in the 5.5-km² Cape Rodney to Okakari Point (CROP) Marine Reserve, a no-take area in New Zealand. Prior fish-count research had indicated that density of snapper inside the reserve was 16 times greater than in adjacent fished areas, suggesting a degree of site fidelity within the CROP reserve. Such fidelity was apparent in Parsons' study, but he also discovered that there was considerable home-range overlap within the population, a previously unrecognized behavior. Furthermore, snapper individuals tagged in the study resided in home ranges two orders of magnitude smaller than documented in prior decades.

Parsons acknowledges that the same species may have larger home ranges elsewhere. "The snapper we tagged were reef residents," he says. "Snapper tagged in previous studies have been 'school' snapper that spend a lot of time over soft sediment bottoms, where there are fewer resources per unit area. Therefore, one would expect their movement to be more expansive to encompass the same amount of resources." Some researchers have suggested that school snapper may have home ranges of 25 km in diameter, he says.

Even within Parsons' sampling of fish in the CROP reserve, there were differing home-range sizes. Again, this variation within a species is consistent with acoustic telemetry studies of other species, like Lindholm's research on Atlantic cod. Over time, says Parsons, reserves could theoretically select for individuals with smaller home ranges, leading to increased concentration within reserves and decreased spillover outside of them. But it may be hard to prove that is occurring - much less plan for it - with so many other factors present, both environmental and population.

"Additional considerations in reserve design include habitat type and conspecific density, both factors that may change after a reserve is established," Parsons says. "With these complications in mind, I am not sure that so much effort should be placed on the design of marine reserves instead of on just trying to create them."

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**BOX: Challenges in acoustic telemetry**

Although acoustic telemetry holds great promise for marine reserve research, the technology presents certain challenges. James Lindholm, a biologist at the US-based Pfleger Institute of Environmental Research (PIER), says the main challenges are a combination of logistical concerns and equipment costs - both influenced by the nature of a research project.

To build an array of receivers in a reserve, the number of receivers will depend on the reserve size, depth of study area, and the species being tracked, among other factors. "If a reserve is tens to hundreds of kilometers in area, the number of receivers necessary to track fish across its boundaries may be prohibitively expensive," says Lindholm. (The receivers can be thousands of US dollars each.)

If a reserve is offshore or at a remote island, the boat time necessary to service the array and download data may be expensive, too. And the effective range of receivers can vary depending on environmental conditions, including ambient noise and water density. Lindholm says receiver range has been measured at 20 m in Indonesia, and 1 km in Antarctica. As a result, use of the technology may be more cost-effective in some areas than in others.

PIER maintains a total of 80 acoustic receivers in waters off California's Channel Islands, one of the institute's study areas for acoustic telemetry. "We are out at sea for several weeks at six-month intervals to download data and replace batteries," says Lindholm. "Despite the challenges, solid experimental design and good planning make using acoustic telemetry more than worthwhile."

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**BOX: Other applications of acoustic telemetry for MPAs**

Beyond indicating fish movement, acoustic telemetry can provide other information of potential use to MPA practitioners:

- The receiver buoys that relay data from tagged fish to shore computers can be outfitted to record environmental changes in real time, such as temperature, salinity, tide height, current direction, and current speed. Such data can be compared to fish movements and distribution to better understand how these factors affect fish behavior.
- Acoustic tags can be attached to video cameras of researchers to allow for geo-referenced surveys of benthic habitat, accurate to 1-2 m.
- The tags can also be attached to recreational divers, allowing for monitoring of visitor location for safety and control. A transmitter on dive gear or a dive boat, for example, could monitor visitor compliance with various regulations, such as no-diving zones. With some adaptation, the tags could also monitor respiration rates and fin-beat frequency of divers, relaying this safety-related information back to the boat.


**BOX: Using satellite tagging to protect highly migratory species**

The most sophisticated electronic tags communicate with satellites orbiting Earth, providing data on a tagged animal's position, vertical movements, and thermal history. Because these tags are relatively effective in some areas than in others. If a reserve is offshore or at a remote island, the boat time necessary to service the array and download data may be expensive, too. And the effective range of receivers can vary depending on environmental conditions, including ambient noise and water density. Lindholm says receiver range has been measured at 20 m in Indonesia, and 1 km in Antarctica. As a result, use of the technology may be more cost-effective in some areas than in others.

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