History of Marine Mammal Tagging

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Introduction

This brief review is just that - a far from definitive overview of the development of tagging as a tool for studying marine mammals, based on a quick and superficial review of the literature. My intention is simply to give participants a broad appreciation for some of the questions that have been addressed by tagging, what kinds of challenges have arisen in designing and applying tags to wild marine mammals, and where things stand at present in terms of tag development and deployment.

Two sets of relatively new tools have already begun to re-define our understanding of marine mammals. The first is "genetic ecology," encompassing techniques to examine distant and recent lineages, DNA fingerprinting, and sex determination. Although too often marketed and construed as "a kind of universal panacea for troubled behavioural ecologists and population biologists" (Hoelzel 1991), genetics does indeed open up exciting new possibilities in many areas of management-related research, especially when used in combination with more traditional approaches. The second is radio telemetry and microprocessor technology. Like genetics, tagging can greatly speed up and broaden the return on investment in field time. Tags are most powerful, in many respects, when linked to satellite-based data retrieval systems and when used to supplement other approaches. Just as photo-identification techniques and the establishment of long-term field studies of populations revolutionized marine mammal research in the 1970s and 1980s, genetics and innovative tagging/tracking techniques provide, in the 1990s, an entirely new framework for understanding the behavior and physiology of individuals and the structures and histories of populations.

As a crude way of gauging the impact of radio telemetry on the field of marine mammal research, I classified the 542 abstracts presented at the recent World Marine Mammal Science Conference in Monaco (January 1998). To my surprise, only 59 of the presentations (about 11%) directly involved tagging, and of these close to two-thirds were targeted at pinnipeds. Interestingly, only 35 of the papers (6-7%) involved genetic analyses. While genetics, radio telemetry, and time-depth microprocessors have certainly made their mark on this field, they have clearly not swamped other approaches to research.

In 1987 a workshop sponsored by the U.S. Minerals Management Service assessed the state of the art for tracking whales (Montgomery 1987), and in 1992 another workshop, jointly sponsored by the Office of Naval Research, Minerals Management Service, National Marine Fisheries Service, and Marine Mammal Commission, re-assessed tagging and tracking technology for marine mammals and developed a long list of recommendations (Anonymous 1992). Major advances have been made, of course, since 1992, many of which are reflected in the recent special issue of *Marine Technology Society Journal* (Stone and Kraus 1998).

Early History of Tagging

The history of marine mammal tagging began with the era of whaling in the Antarctic and sealing in the North Atlantic (harp seals) and North Pacific (fur seals). The Discovery Committee, established in 1924, undertook a massive program of marking whales in the Southern Ocean (Rayner 1940). As N.A. Mackintosh (1965:17-18), a key figure in the work of that committee, stated: "The importance of finding a means of marking whales for evidence on their movements and migrations had been recognized from the start in both England and Norway, and indeed as the one means of identifying a whale on two occasions separated by a known period, it provides indispensable evidence not only on migrations but on the distribution and segregation of the stocks, age determination, rates of mortality, and the timing of events in a whale’s life." Indeed, the Discovery tag - a stainless steel tube, bearing a serial number and offer of a reward, shot with a .12 bore shotgun into the whale’s blubber - was responsible for a very considerable part of what was known about the movements and life histories of the great whales before the 1970s. Since then, photo-identification (e.g., Hammond et al. 1990) and more recently "biopsy tagging" (e.g., Palsb¿ll et al. 1997) have eclipsed conventional marking as tools for addressing some of those same questions, without the need for killing the research subjects to get answers. Many kinds of "static" marks or tags have been used as well, including spaghetti streamers, button or disc tags placed on the dorsal fin, freeze brands, and notches cut into the dorsal fin (Hobbs 1982, Scott et al. 1990). For most of these (but not spaghetti streamers), it is necessary to capture and restrain the animal for at least a few minutes, and this generally limits their application; they can generally be used only on dolphins, porpoises, and some small toothed whales.

In the case of pinnipeds, the first marking study was probably that undertaken by the Russian overseer on St. Paul Island in the Pribilofs who, in the 1860s, cut the ears off young male fur seals to see whether they returned to the same breeding beaches in subsequent years (the seals, not the ears) (Scheffer, Fiscus and Todd 1984). Later, in 1912, the letter "T" was hot-iron branded on the heads of 5529 North Pacific fur seal pups, apparently to see how many of them returned the next year to their natal beach in the Pribilof Islands (Scheffer et al. 1984:21). More branding and "shearing," and the introduction of tagging (affixing a numbered metal tag to a hind flipper), took place at the Pribilofs after 1940 (Scheffer et al. 1984). A wide array of marking techniques has been used on pinnipeds, involving paints, dyes, or bleach; flipper tags made of plastic, nylon, or metal; tattooing; branding; and scarring or clipping (Erickson et al. 1993). Such marking programs have been used not only for documenting movements and survival, but also for mark-recapture estimates of population abundance (see, for example, Sergeant 1991, for a summary of harp seal estimates). Marking with "vital stains" (notably using antibiotic drugs such as tetracycline) has been used with both cetaceans and pinnipeds to calibrate age-estimation techniques (Myrick and Cornell 1990). For obvious reasons, tag application on pinnipeds is usually much easier than on cetaceans. Pinnipeds can be captured while hauled out, and they can be immobilized with drugs. Neither of these options is available in the case of cetaceans.

Telemetry Tagging

Radio-telemetric studies of whales and dolphins began in the 1960s with the pioneering work of Schevill and Watkins (1966) at Woods Hole and Norris, Evans and Ray (1974) in California.

Watkins and Schevill (1977) regarded the primary requirements of a whale radio tag to be that: (a) an identifying signal is transmitted whenever the whale is at the surface, (b) the tag can be attached from a distance of at least tens of meters, (c) the tag disturbs the whale as little as possible, and (d) the tag lasts long enough to provide information over a substantial segment of the whale's life pattern, preferably at least 13-14 months. After more than 20 years of development and field testing (e.g., Watkins 1979; Watkins et al. 1981, 1984; Watkins and Tyack 1991), the Watkins group has made progress on all of these desiderata. In their most recent effort, a fin whale was satellite-tracked for 45 days (Watkins et al. 1996). In this instance, the authors were able to infer that the limiting factor was tag retention rather than battery life or any design flaw. The Watkins tag is fired into the whale using a shoulder gun.

Attachment has always been a major problem for large whales because it is generally impossible to catch and restrain them. Belly bands (Norris and Gentry 1974, Norris et al. 1977), and in one exceptional instance surgical sutures (Evans 1974; Sweeney and Mattsson 1974), have been used on young gray whales to attach transmitters for relatively short times. Mate et al. (1983) developed and tested a device for attaching a radio-transmitter with twin umbrella anchors, driven into the whale's blubber by two electrically-actuated pressure cartridges. A 5 m-long aluminum pole was used for applying the tag, so the animal had to be approached to within about 3-4 m of the boat. A more recent Mate tag uses stainless steel rods, tipped with double-edged blades and folding toggles, to anchor the cylindrical transmitter housing and antenna (Mate et al. 1997). Attachment is achieved using a compound crossbow, allowing deployment from distances up to 10 m.

Once attachment has been accomplished, tag retention becomes a major problem. Not only does the skin naturally react to sequester and expel foreign objects, but also the area around the wound can become weakened by infection with bacteria carried in with the implant, and the opening left behind by any implant becomes a gateway for infectious organisms from the sea. Some work has been done with cetaceans to evaluate the process by which foreign objects in tissue are rejected (Geraci and Smith 1990).

Opportunities to attach transmitters to smaller cetaceans are much more frequent, or easily arranged, than is the case with sperm and baleen whales. Those species with a substantial dorsal fin were the first experimental subjects (Leatherwood and Evans 1979; Irvine et al. 1982; Scott et al. 1990). Radios, usually mounted on molded plastic or fiberglass saddles, were spring-bolted to the animal's fin using aluminum, magnesium, or zinc nuts, and later delrin or other synthetic pins with stainless-steel nuts. This basic design continues to be employed with ongoing refinements (e.g., Mate et al. 1995). A major challenge arose with those species lacking a dorsal fin, most notably the beluga and narwhal (little effort has been devoted to tagging programs with other finless small cetaceans). Frost et al. (1985) were able to obtain some information from VHF transmitters pinned "backpack-style" to the dorsal ridges of belugas, but those initial efforts have given way to a now standard satellite-linked system (transmitter and antenna, pressure transducer, and microprocessor) for belugas and at least female narwhals designed and applied by A.R. Martin and others (Martin and Smith 1992; Martin et al. 1993, 1994; Smith and Martin 1994; Richard et al. 1998; Heide-J¿rgensen et al. 1998). Narwhal tagging has come to include attachment of the transmitter package to the base of the adult male's tusk, as well as the "backpack" to the dorsal ridge of females and juveniles (Dietz and Heide-J¿rgensen 1995; Heide-J¿rgensen and Dietz 1995).

Remote deployment of suction-cup tags on small cetaceans has recently been accomplished (see below), but long-term attachment on small cetaceans, including devices that are satellite-linked, requires capture and restraint. Salvaged strandlings that have been rehabilitated in captivity have provided numerous opportunities to test radio tags on pilot whales and dolphins (e.g., Mate 1989a, 1989b; Mate et al.1994; Davis et al. 1996).

Bio-telemetry of pinnipeds emerged during the 1960s as a powerful new tool, or set of tools, for studying seal physiology and behavior, as well as for tracking the animals' movements (McGinnis 1968; Bengtson 1993). The attachment of instruments to pinnipeds is much more straightforward than it is with cetaceans. A standard means of instrument attachment has been to use quick-setting epoxy to glue the devices to the dorsal hair of recently molted individuals (Stewart et al. 1989; Heide-J¿rgensen et al. 1992). VHF and UHF transmitters, acoustic tags, and recoverable data-loggers have been used on an almost routine basis with many species.

Serious efforts to radio-track sirenians did not begin until the late 1970s, initially with a transmitter belt-mounted on the tail stock, and later with a tethered floating transmitter unit designed for use with both manatees and dugongs (Rathbun, Reid and Bourassa 1987; Rathbun, Reid and Tas'an 1987). VHF radio transmitters and satellite-linked platform transmitter terminals have been used for routine tracking of manatees in the southeastern United States (Reid et al. 1995). The primary purpose has been to identify areas of high use that need special protection. An unusual feature of the manatee tagging program in Florida is that instrumented animals are often re-captured and their tags replaced, repaired, or adjusted (Reid et al. 1995). The most recent deployments of manatee tags have incorporated satellite-monitored transmitters for long-distance tracking and VHF and ultrasonic transmitters for field tracking and data recovery (Deutsch et al. 1998).

Food for Thought

In general, remote deployment of tags is necessary for the large whales and almost never necessary for pinnipeds, otters, or sirenians, all of which can be captured and, if necessary, narcotized (at least in the case of pinnipeds), with relative ease. In the case of small and medium-sized cetaceans, remote deployment is done occasionally. Stone et al. (1994) were the first to attach small, retrievable, suction-cup tags to dolphins using a pole applicator. Baird (1998) summarized efforts at remote deployment of suction-cup tags on everything from bow-riding Dall's porpoises and bottlenose dolphins to the deep-diving northern bottlenose and short-finned pilot whales. A cross-bow was used to attach the tags to the larger, non-bow-riding species, while a pole was used for the smaller bow-riding animals. Suction-cup tags are not designed for longevity and seldom remain attached for longer than a few days. The main benefits of such tags are that they are non-invasive and relatively economical, and they provide high-resolution data on location, diving behavior, swim speed, etc. Thus far, it has not been possible to achieve remote deployment of long-term devices to cetaceans smaller than gray whales. The animals need to be captured (or salvaged from fishing gear, or after stranding) for instrumentation. It is important to consider that the greatest risk to cetaceans subject to tagging occurs during the capture process. The shorter the tag-retention time, the more captures that are necessary to obtain meaningful results from the tagging program, and thus the greater the risk of mortality or injury to the animals.

There has been considerable controversy, especially among marine mammal scientists, about the impacts of tagging on individuals and populations. Are the risks to the animals and their populations worth it? This is a subject of potentially endless discussion (cf. Young 1996). In cases involving species that are especially charismatic (e.g., dolphins) or populations or species that are endangered (e.g., some whale, dolphin, and seal species and populations), feelings are intense. Quite apart from the ethical issues, important scientific questions also come into play. If tagging (and the associated chasing, capture, handling, etc.) does affect the tagged animal's subsequent behavior and/or fitness, then how representative are the findings from the research? Martin and da Silva (1998) had exceptional opportunities to resight, and in some instance recapture and examine, river dolphins that had been tagged and radio-monitored in the Brazilian Amazon. The results of their observations were encouraging, as no debilitation or tissue damage was evident, and the life history and behavior of the tagged animals appeared normal. This has generally been reported for other tagging studies as well.

The question of how representative a tagged individual, or even a number of tagged individuals, are of the population is an important one, and the answer seems to vary with the species, and perhaps with the population. In the case of white whales, Smith and Martin (1994) found that whenever they made the effort to fly to an area where one or more of their radio-tagged animals were located, they found hundreds or thousands of white whales in the vicinity. Their conclusion: "We are confident that even this small sample of tagged animals (in relation to the population size) has been adequate to describe in broad terms the behaviour of the population as a whole" (also see Martin et al. 1993). Further satellite tracking of white whales in different areas has suggested that each geographical population (Mackenzie Delta, eastern Canadian Arctic, Svalbard, western Hudson Bay) has its own characteristic movement pattern, with no obvious similarity in their respective summer feeding and fall migration strategies (A.R. Martin, pers. comm.). Pinniped studies using recoverable time-depth recorders have become sufficiently "routine" to allow researchers to explore questions of variability and representativeness of diving data (Boveng et al. 1996).

Scott et al. (1990) made an interesting comment in weighing the benefits of satellite vs. radio tracking: As field biologists, we see a somewhat intangible benefit of radiotracking which may make it preferable over satellite tracking. Nothing can give one a 'feel' for how an animal lives better than by dogging its flukeprints continuously for periods of days or weeks. On-the-spot interpretations of behavior displayed by the tagged animal and its associates at a particular time and location allow the field biologist to develop a sense for what is important in the day-to-day life of the animal. Regular observations of the tagged animal allow the researcher to judge whether the data being received are accurate and whether the behavior of the animal is normal." The opinions of these authors were informed, on this occasion, primarily by experience with bottlenose dolphins and other temperate-to-tropical, coastal species. Animals living in less amenable climatic zones and farther offshore, and which migrate over long distances, may be effectively impossible to follow with conventional radio tracking. Satellite-linked tracking does not preclude direct contact with the animal. In fact, one great benefit of satellite tracking is that it enables the researcher to re-contact the tagged animal in order to investigate its social and ecological context. This should be done whenever possible, and efforts to locate and observe tagged animals directly should be incorporated into project designs (and budgets).

Many of the questions addressed by tagging and telemetry programs are obvious. Where do the animals go (in all dimensions, not just horizontally) and how fast? How do their movements change through the day or between seasons? Other questions are often tailored to the species and are less obvious. For example, in the case of belugas and narwhals, the question of what proportion of the animal's time is spent at or near the surface has been central to funding. Hunters and hunt managers are interested in knowing how to adjust ("correct" or calibrate) survey data to account for availability bias (i.e., submergence times) (see, for example, Frost et al. 1985; Martin and Smith 1992; IWC 1992). The tracking of harbor porpoises in the Gulf of Maine and Bay of Fundy (Read and Westgate 1997; Westgate and Read 1998) and of white whales and narwhals in the Arctic has contributed to understanding stock boundaries, with obvious value to those charged with managing bycatch (porpoises) or hunting (belugas and narwhals).

In the case of porpoises, the data on individual animal movements also demonstrated the inadequacies of management strategies such as area or seasonal fishery closures. Similarly, the unexpectedly high mobility of right whales in summer and fall, demonstrated by satellite-tracking, calls into question the effectiveness of measures to relocate shipping lanes or restrict fishing in order to reduce collisions and entanglements, respectively (Mate et al. 1997). This raises an interesting question: Can telemetry really deliver on its promise of providing valuable insights about "critical habitat," which can then be given protection (e.g., see Mate 1989a, 1989b)? Or will it, at least in some instances, only demonstrate the futility of certain time-honored approaches to marine conservation (e.g., establishment of protected areas), prolonging and complicating the search for effective options?

Baird (1998), referring specifically to field studies of odontocete cetaceans, makes the distinction between the coarse-level data obtained from satellite-linked telemetry and the high-resolution data obtained from recoverable time-depth recorders. He argues that sufficient data on surfacing and diving behavior can be obtained from the relatively brief deployments (hours, or a few days, at most) of the latter to address some management-related questions (e.g., survey calibration, exposure to depth-specific threats such as fishing gear, vessels, and noise), as well as reveal aspects of basic biology. The dynamic between these two tagging options presents interesting challenges. Investigators committed to suction-cup attachment and the use of recoverable data-loggers offer high-quality data that are limited in geographic and temporal scope, while those committed to satellite-tracking promise continuous streams of data covering large spatial and temporal scales, but with attendant problems of high cost per deployment, tag rejection, battery failure, and imprecise satellite locations. Both groups must sample creatively and keep on tinkering.

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