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RADIO-TAGGING OF WHALES

by

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TECHNICAL REPORT

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RADIO-TAGGING OF WHALES

Abstract

We recount here a series of attempts to tag and track whales at sea without catching them. Radio transmitters of 140 Mc were attached to the backs of whales from helicopters. Tracking the tagged whales was attempted by ship and by airplane receiving systems.

The problem

When Europeans first came to North America, Eubalaena glacialis, the right whale, was found along the Atlantic coast, and was especially abundant near Cape Cod. By 1700 the whalers had greatly reduced the population, so that these whales have since been so scarce that they have long been thought virtually extinct. But during the last decade and a half they have again been reported along our coast, both in Florida and Massachusetts. In Florida the reports have been from January through March, and in Massachusetts from January into May, but mostly late March and April. After early May they seem to disappear, we do not know whither. We have found no record of them on the Grand Banks (except one recent unconfirmed assertion), not even in the old fishermen's accounts. At Cape Cod we have occasionally recognized a particular whale after one or two years, so that we know that they have a definite migration circuit. But where do they spend the rest of the year?

Since this species is no longer hunted commercially, the usual "Discovery" whale mark is of no use to us. These marks are fired into whales from a gun,

and are not recovered until the whale is cut up and cooked. We therefore considered tags that could be recognized without killing and cutting up the whale. Conspicuous visual marks were an early suggestion, such as buoyant yellow line, buoys, and balloons. We have not worked very hard at these because of the small likelihood of useful reports from ships. Sailors just don't seem to pay much attention to whales.

As practitioners of underwater sound, we naturally thought of attaching acoustic beacons to the whales, but did little about it for several reasons. One was the probability that it would annoy the whales (no signal useful to us could be expected to be outside the whales' range of hearing), perhaps as a tin-can on a dog's tail. An attached noise-maker might even get the whale driven off by his mates, so that one might be tracking an outcast, not the main bunch. Other reasons were the instrumental and operational awkwardnesses of handling a directional receiver for as low a frequency as we would have to use to achieve long ranges, not to mention devising a suitably powerful source that would not wear out the whale; then there were the difficulties of detecting and tracking this sort of signal from a ship.

This brought us to radio.

We were unable to discover any equipment already adapted to our purpose, and so had to convert and contrive as we went along, conducting tests with a variety of frequencies, instrument sizes, antennae, and receiving arrangements. We describe only those units that appeared to offer a chance of success. These included modified transmitters and receivers that were originally designed for

pigeon-tracking (American Electronic Laboratories, Inc., Instruction Manual for animal tracking system, Technical report for Office of Naval Research, Biology Branch.(Contract Nonr-2835), Colmar, Pa., 13 pp.), supplied by the Office of Naval Research, Biology Branch. Other units were designed and constructed at Woods Hole by the junior author. As the radio systems were developed, they were tested both in the laboratory and at sea as realistically as possible. The receiving systems will be described first, then the transmitters and the actual tagging.

Receiving system

A receiving system that will permit tracking of radio-tagged whales has special requirements. It must give a bearing on a very short and intermittent signal, and it must be efficient enough to receive the one milliwatt transmitter signal at a distance. Standard direction-finding techniques are not usable since the signals are too short for reliable null or beam detection systems, and the signals are too weak for the relatively inefficient goniometer and phase detection systems.

Our whale tag transmitter operates at 140 Mc at a power of one milliwatt, and the signal is radiated, of course, only when the whale surfaces with the antenna out of water. It is estimated that a two-second burst would be the longest probable signal from the whale, with most exposures being only momentary and very intermittent; periods between signals would vary from 30 seconds to 10 or 15 minutes or longer. A rapid indication of bearing, therefore, is an essential, and accuracy of bearing is relatively unimportant. Since the

signal must be received from a moving ship or plane, the purpose is to locate and stay with the animal, rather than to track from several fixed stations. The latter seems impractical because of the long distances to shore and the extreme antenna heights that would be necessary, not to mention the minute signal that is transmitted; this is limited by the size of the package put on the whale.

Multiple antennae giving directional indications that cover the full 360° field of the tracking vehicle appear to fit these requirements best. Two systems have been used. One is a shipboard installation providing bearings to 15° accuracy, but limited to fairly close range, 6 km. The other is an air-borne system giving only rough 90° bearings but with a range of more than 80 km.

Shipboard system

The first antenna array, used during the 1962 tagging attempt, was composed of six vertical dipoles in six shallow 60° corner reflectors, arranged concentrically around a supporting mast. This system was mounted 15 meters above the water on the R/V BEAR (Figure 1). Each antenna fed a separate receiver and each receiver responded to a signal by giving an audio tone, indicating relative strength on a signal intensity meter, and relaying a trigger signal to one channel of a six-channel event-recorder. The event-recorder produced a mark on a slow-moving paper strip, providing an indication of the antenna that received the signal and the time between signals.

The frames of the corner reflector were made of welded 3 mm aluminum

angle (2.5 x 2.5 cm). The reflector screening was dipped-galvanized poultry wire. Each side of the corner reflector was a 117 cm square. Spreaders mounted both top and bottom fixed the antenna 63.5 cm from the corner. The antenna was a folded dipole constructed of 300-ohm twin-lead suspended inside a 1.5 cm polyvinyl chloride pipe.

The receivers used in this system were developed by American Electronic Laboratories, Inc., for their "pigeon tracking system". They provided better than a 0.1 microvolt sensitivity and were used with only one minor modification. The monitor output jack was disconnected and connected to the meter signal circuit to provide a triggering potential for the event-recorder.

The event-recorder was built from the basic chassis of a Rustrak Recorder (Rustrak Instrument Co., Inc.). Seven hot-wire pens (Sanborn) were modified and mounted on the recorder, one pen for timing marks and six for the receivers.

Because of reflections from adjacent waves, bearing was not reliable when the transmitter was close to the ship. But at 1 km or more it gave quick bearing indications accurate to about 15° on intermittent signals.

The range of this system with a receiving antenna height of 15 m and the transmitter floating on the sea surface was limited to about 6 km. At 6.5 km small wavelets appeared to intercept the signal, and by 7 km the signal could only be received occasionally as the transmitter was carried on the crest of a wave. Since these ranges seemed so much shorter than those forecast for visibility over the curvature of the earth they were verified visually with binoculars from the antenna position: when the large orange

float attached to the transmitter was visible, the signal was also received, but whenever a wave hid the float, the signal was interrupted.

During one of the tagging excursions, the helicopter, carrying whale tags which were inadvertently transmitting, was tracked as it circled the area around the ship and then went off for fuel. With the transmitters at an altitude of less than 300 m aboard the helicopter, a strong constant signal with good bearings was maintained until the helicopter disappeared behind hills as it prepared to land at a distance of over 40 km.

Air-borne system

Because of the deficiencies of the shipboard system, an air-borne receiving system was used for the 1964 tagging program. This consisted of four two-element antennae mounted on the WHOI Helio-Courier, a float plane capable of slow speeds (as low as 55 km/hr). Each antenna was composed of a quarter-wave stub with one reflector stub. One of these 2-element arrays was mounted under each wing, giving directionality to either side. Under the body of the plane a combination array of one reflector between two antennae provided bearing indications fore and aft. (See Figures 2 and 3.)

Each of the four antennae fed separate receivers and each receiver was connected to one channel of the event-recorder. Both receivers and recorder were the same as were used on the previous ship installation. Bearings during a long burst of signal within 10 km could be read to 45° — very short bursts were limited to 90° . Good bearings could be maintained even within a few hundred meters of the transmitter if the plane's altitude was such that the

signal was received nearly horizontally and the receiver gains were attenuated. Directly overhead all four antennae registered nearly equal amounts of signal. These bearings could be read reliably only while the plane was in level flight, however. Banking and tilting the plane upset the antenna reception patterns. In fact, a steep bank when the plane was turning sharply toward the transmitter completely cut off reception on all four antennae.

The range limit for reliable reception of the 140 Mc signal with the transmitter floating on the water depends both on the altitude of the plane and the sea state or wave height. Local wave-interference becomes pronounced at low angles of radiation, as when listening from a distance. Waves fifty centimeters high at a 30 km transmitter-to-receiver distance transform a steady transmitted signal into an unreadable one at a 300 m receiver height; but with a calm sea, at 300 m altitude, a good steady bearing may be received at the same distance. At any given altitude before actually losing the signal, as the plane opened range on the floating transmitter, the reception would become increasingly intermittent due to interfering waves.

The reception ranges obtained at various altitudes were consistently much shorter than those that were anticipated due to the earth's curvature. The following ranges were those noted during a trial run at zero sea-state, and are the distances at which the first bit of intermittent reception was noted for each altitude. The one-milliwatt 140 Mc transmitter here again was floating with the top of its quarter-wave whip antenna no more than 60 cm above the surface of the water. The transmitter was located near the western end of Nantucket Sound, and the plane was flying east.

At 150 meters altitude the approximate range was 20 km

300 m	32 "
600 m	45 "
900 m	57 "
1200 m	70 "
1500 m	80 "

At 80 km the signal was still quite readable with greater altitude.

These ranges proved to be repeatable with a steady transmitted signal, and provided a means of estimating distance from the transmitter. The change in reception from a steady signal to an intermittent signal occurred within a very short space of time, 15 to 30 seconds at a 150 km/hr plane speed. These ranges were reliable within about 3 km at a given sea-state. The intermittent quality of a radio attached to a whale, however, would preclude any such range information, although relative signal strength might provide a rough indication of range if the signal bursts were long.

Towed antenna

The air-borne antenna system described above was affixed to the plane by appropriate pads and brackets, and required special licensing and approval by the Federal Aviation Agency. A system that does not require modification to the plane obviously would make it easier to obtain permits for its use. With a self contained antenna system, any aircraft could be used to track the animals. Less expensive planes could be operated for near-shore tracking,

with more expensive longer range planes in use as the whale moved farther and farther out to sea.

We have tested an antenna designed to be used from any aircraft having a 25 cm hatch or a door through which it could be lowered in flight. This small towed antenna-array is a comparatively inefficient system, but its versatility may outweigh this feature. It was built of eight fiberglass rings, 25 cm in diameter, interconnected by wires composing the antenna and reflector elements (Figure 4). It may be collapsed and stowed in a small space. An 11.5 kg lead weight was suspended a little more than a meter below the antenna to keep the array nearly vertical. The antenna was towed about 15 meters below the plane. At speeds up to 157 km/hr the antenna remained steady. Electrically, it is four quarter-wave antennae, each set in very shallow 90° corner reflectors. Within 5 km of the transmitter, the signal is received on two or three antennae so that directionality may be read best by the lack of signal on the antenna facing the opposite bearing. Beyond about 5 km only the antenna nearest the transmitter responds. Range is limited to about 35 km, due apparently to the inefficiency of the shallow reflectors. Within this distance, the characteristics of onset of intermittent signal with increasing range at low altitudes, as described above, was noted.

The 140 Mc frequency appears to be a quiet frequency at sea, and during all of the monitoring done away from shore, the background noise levels remained low.

Transmitters and tagging

The transmitters and the actual tagging attempts are discussed together, because the successive models of transmitters were direct results of tagging experience, even more so than the changes in receiver systems.

We had observed in Cape Cod Bay that the right whales often spent a good deal of time at the surface, so that it seemed possible to attach the radios then. It would be important to place them nearly on the mid-line over the thorax to insure maximum exposure (the signal would of course radiate only when the antenna was in the air). As the surest way of placing the radios correctly we selected helicopters, and were extremely fortunate in having the support of Commander, Fleet Air Atlantic, who furnished us with Navy helicopters from Quonset Point, Rhode Island.

The transmitters were 140 Mc one-milliwatt transmitters with quarter wavelength (50 cm) whip antennae. To convert the transmitters for our use, they were put with a two-week battery supply in cylindrical aluminum pressure cases 4.8 x 21.5 cm, tested to about 70 kg/cm^2 , or for about 700 m depth, and probably good for half again this depth. They had two crossbars to insure the radio sitting antenna-side-up on the whale's back. To hold it in place we attached a swordfish toggle dart on 25 cm of light rubber shock-cord. All this was mounted (with fastenings to break on impact) on a standard swordfish pole and shank with a crossbar 46 cm from the tip; this limited the penetration so that the dart would toggle at a depth of 33 cm (hopefully immediately under the blubber), at which distance the shock cord was stretched

just hard enough to hold the radio firmly against the skin. This entire assembly weighed 5.5 kg, of which the radio tag was 800 g; it was slightly heavy in water. Figure 5 shows the tag and dart, with styrofoam floats so that it could be recovered in case of a miss (these floats detached on striking the whale). The pole with transmitter mounted was hand-held by the harpooner leaning out of the helicopter; he dropped it on passing slowly over the surfaced whale at 6 m altitude, retrieving the pole by a light line.

On 7 May 1962, after three weeks of bad weather that kept our airplanes grounded, the WHOI Helio-Courier (Robert Weeks, pilot) found a right whale near Wood End, Provincetown. Weeks vectored the Navy helicopter to the whale, and after several passes a successful drop was made. The whale sounded immediately as the helicopter went upstairs; shortly the whale soused 5 m out of water and thrashed about. The orange-painted transmitter could be seen from aircraft and ship, and was properly sited with the white antenna insulator intact. But nothing was heard from the radio tag, probably because of a combination of factors: (a) the spare tag transmitters in the helicopter were operating on the same frequency and could not be turned off for some time, (b) the whale disappeared shortly after it was tagged and presumably moved out of the area (it was not found in three days of searching by plane, helicopter, and ship), (c) the receiving system was too short-range — only 6 to 6.5 km at this line-of-sight frequency and the 15 m antenna height.

That was the last whale of the season.

Second attempt

Discouraged by the short range obtained even in favorable tests, we decided to take the "line-of-sight" feature literally, and added a brilliant electronic flash to the next tag. Again we used a 1-milliwatt 140 Mc radio transmitter; this time a salt water shorting circuit turned off both radio and light when submerged, thus saving battery space and weight. Even so, the 1964 tag was much bulkier than our first model. It was in a cylindrical aluminum pressure case, 9 x 29 cm. The teflon antenna insulator was located on top at the after end of the case and the glass dome housing for the electronic flash was mounted at the forward end. See Figures 6 and 7. The salt-water switch electrode insulated by a teflon sleeve was directly behind the light dome. The pressure case was painted bright orange. The complete tag weighed 3.8 kg in air, 1.2 kg in water.

The attaching mechanism was again a swordfish dart on 25 cm of rubber shock cord attached to the forward foot of the tag. And, as before, it was mounted on an iron shank on a wooden pole, with the same blubber penetration stop. To our dismay we found none of the Eubalaena (right whales) lying at the surface with their backs exposed, as we had so often seen them before. This year each one we found brought only the top of the head (the nose) to the surface, with the body hanging down so that even the shoulders were 2 m or more under water. It was out of the question for our bulky package to sink fast enough to reach the whales or to hit hard enough to fasten through so much water. We made several despairing drops, but completely in vain.

We found several groups of whales, but could touch none. Again the last were seen on 7 May; beginning next morning, two Navy helicopters and our float plane searched 20,000 km², and found no whales; no more whales were found that season.

Third attempt

After the 1964 experience it was clear that we needed a tag that would fall through several meters of water with enough force to penetrate the whale's skin. The 1965 model was in an aluminum tube only 1.5 cm in outside diameter and 15.5 cm long (Figures 8 and 9). It had a control circuit to clamp the transmitter off while submerged (drawing less than 0.1 ma, see schematic, Figure 10). The battery life was calculated to last about 10 days if the transmitter ran continuously — months if the whale acted normally and spent most of its time underwater. The tag weighed only 75 g in air, and cost approximately \$50 apiece.

This time the fastening was different, since the new tag was intended to be buried vertically in the blubber with only the teflon insulator and the antenna projecting. Accordingly a barbed aluminum point was attached rigidly 6 cm below the end of the case (Figure 8). As before, a swordfish shank fitted into a hole in the point, and the tag was attached to the shank with weak rubber bands. The penetration-limiting crossbar on the shank was only 25 cm from the tip.

Again (May 1965) we found the whales not fully surfaced, and by the time the helicopter was over them, they were sinking through disturbed and

foamy water that made accurate drops difficult. Nevertheless, with the determined skill of Lt. Cdr. Ronald R. Oberle, USN, we had some good opportunities. We believe that we struck three whales, each time so deep that the 2.6 m pole disappeared completely underwater; however only one of these had the mark properly planted high on the back. But no radio signal was picked up by the tracking plane. The helicopter party could never approach this whale closely again, but the tracking plane could, and inspection through binoculars showed damage to the teflon insulator. Probably this was inflicted by the withdrawing iron shank; each time it came back bent by the violent twistings of the victim.

Summary

We have demonstrated that Eubalaena glacialis (right whale) may be approached by helicopter closely enough to permit manual attachment of tracking devices. (To how many other kinds of whales this applies we do not know, though we do know that Balaenoptera physalus (finback whale) is very difficult indeed to approach in this manner.)

The remainder of the exercise has been less successful. Although we believe our preliminary tests have shown our transmitters to be rugged, we have failed to hear them once they were attached to a whale. We point out that we have had only two good chances. We will have to try again, if possible with improved equipment.

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Figure 1. The ship antenna mounted 15 m high on the R/V BEAR was composed of six corner reflectors.

Figure 2. The starboard wing-antenna mounted on the Helio-Courier was made up of quarter-wave stubs. The outboard stub was insulated and served as the antenna; the inboard unit was connected to the metal wing and served as a tuned reflector.

Figure 3. The belly-antenna on the Helio-Courier had 3 quarter-wave stubs. The center stub was a tuned reflector, connected electrically to the plane. The other two antennae were insulated, giving fore and aft bearings.

Figure 4. The towed antenna system was designed to be lowered out of the plane's camera hatch. It consisted of 4 shallow corner reflectors. The vanes help stabilize the antenna.

Figure 5. Whale tag transmitter used during the 1962 season, with swordfish toggle and detachable floats. The pressure case was 4.8 x 21.5 cm.

Figure 6. The 1964 whale tag included an electronic-flash light as well as the transmitter. The clip lead is shorting the salt water switch to turn the entire assembly off. The pressure case was 9 cm x 29 cm.

Figure 8. The 1965 whale tag was designed to penetrate water to tag submerged whales. Pressure case 1.5 x 15.5 cm.

Figure 9. The components of the 1965 whale tag include the very compact transmitter, batteries, antenna, insulator, and pressure case.

Figure 10. The schematic diagram of the 1965 tag transmitter shows values that take into account the high capacitances due to close proximity of adjacent parts.

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