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# DESIGN AND TESTING OFA NEW RADIO-TAG FOR INSTRUMENTING LARGE WHALES

Final Report

Prepared for

U. S. Department of the Interior
Bureau of Land Management
Alaska OCS Office
Anchorage, Alaska

Under

AA851-CT9-34
Contract ~~AA-730-79-4120-0109~~
with Oregon State University

Prepared by

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Institute of Arctic Biology
University of Alaska
Fairbanks

March 1981

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# INTRODUCTION

## Background

In August 1978, PROJECT WHALES was initiated by the Bureau of Land Management (BLM) through a contract to the Naval Arctic Research Laboratory (NARL) in Barrow, Alaska. The purpose of the study was to investigate the occurrence, ecology and biology of the bowhead whale *(Balaena mysticetus)* and gray whale *(Eschrichtius robustus)* in the Beaufort Sea with emphasis on the proposed Federal/State Beaufort Sea Lease Area.

PROJECT WHALES consisted of several research units one of which (RU379) entailed the development of a radio-dart to monitor the movements and behavior of whales. Because both bowhead and gray whales are considered endangered and a new design radio-tag was proposed for use, it was considered important to test the radio-tags prior to deployment in arctic waters. In Fall, 1978, Dr. Bruce Mate of Oregon State University submitted a proposal to the NARL for funding to radio-tag gray whales in Baja, Mexico. Although Mate's tag was of a design different from that proposed for the Beaufort Sea work, it used the same electronics (Telonics, Inc., Mesa, Arizona). Therefore, funding the study through PROJECT WHALES' RU379 was considered justified because it would provide information on the suitability of Telonics radiotransmitters for monitoring large whales. Three adult gray whales were tagged during February-March, 1979 in San Ignacio Lagoon, Baja, Mexico. A report on this study was submitted to PROJECT WHALES (Mate 1980a). Reports on the RU379 work have been prepared through the NARL (Follmann 1979, 1980).

The success of the tagging project in Mexico during 1979 justified continued development of the new radio-dart using the Telonics transmitter. In Fall, 1979, the BLM approved funding for a more extensive gray whale tagging project in Mexico. The project was funded through Oregon State University, and the work that began as RU379 of PROJECT WHALES became a subproject under the new contract. This report concerns the design and testing of a radio-tag using a dart gun for deployment and the results of a gray whale tagging experiment in Mexico during January-February 1980.

## Scope of Work

The design and testing of a radio-tag using a dart gun for deployment and the results of a gray whale tagging experiment in Mexico during January-February, 1980 are presented. The objectives of the whale tagging experiment were:

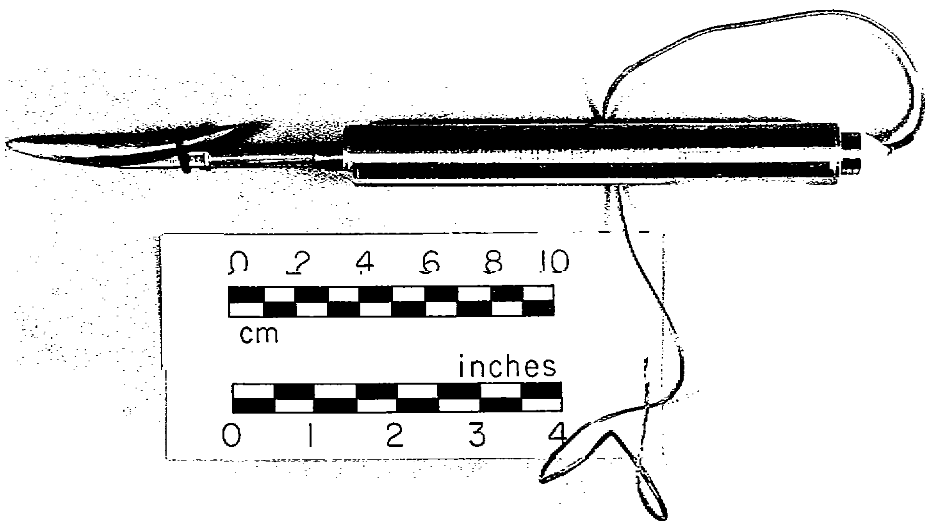
1. Tag up to ten gray whales with the radio-dart.
2. Determine the effectiveness of the attachment procedure for tagging large whales.
3. Determine the length of time that the radio-dart will remain on a whale.
4. Determine the range of reception from tagged whales.

# METHODS AND MATERIALS

## Radio-dart

The radio-tag consists of a dart-like device (Fig. la) which is fired from a gun designed and manufactured to propel syringe-darts for chemical restraint of animals. The tag consists of a cylindrical housing containing the transmitter and batteries and the attachment point. It is 26.5 cm long and has a 44.5 cm long flexible whip antenna extending from the posterior end. For clearance between the dart-tag and the 1.892-cm diameter barrel, the cylinder wall is machined to an outside diameter of 1.879 cm. The total weight averages 100 g. The entire radio-tag including antenna is made of stainless steel. All non-electric components were designed and machined by Manning Machine and Fabrication (Fairbanks, Alaska).

The penetration point and shaft are 10 cm long. The dart is designed to penetrate the skin and blubber to a maximum depth of 10.5 cm, which is the length between the tip of the point and the shoulder of the cylindrical housing. The penetration point is hinged at the end of a shaft and is designed to deploy laterally, as a toggle-type harpoon tip, when it is pulled back (Fig. lb). The toggling of the point orients it perpendicular to the shaft thus locking the tag in place.

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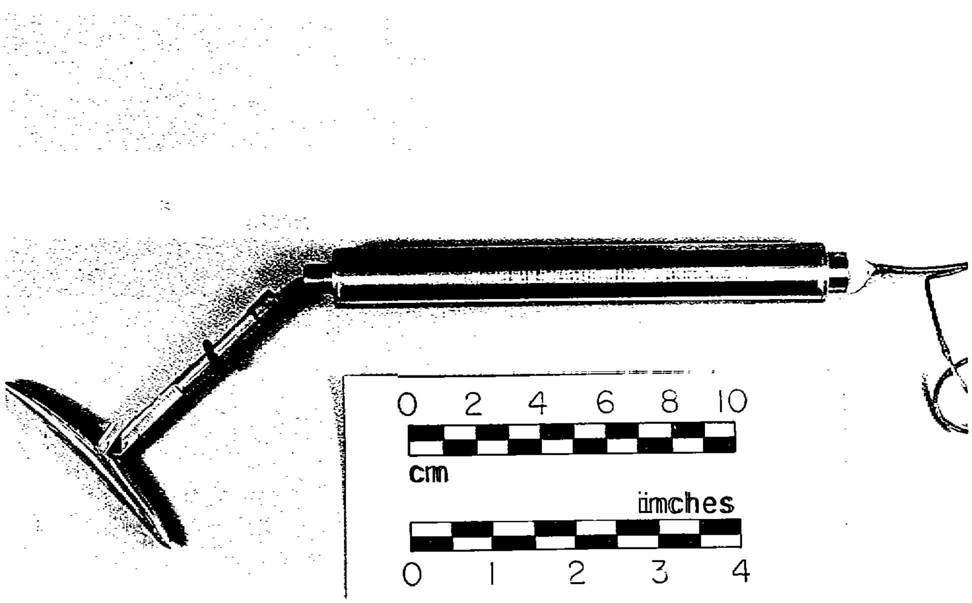


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Figure 1. Radio-dart designed for tagging large whales; (1a) as deployed in barrel; (1b) as deployed on a whale.

The penetrating point is held parallel to the dart's axis during firing by a rubber O-ring or band which is forced off the penetration point as the dart enters the skin.

Because most of the radio-dart does not penetrate the skin, it is important to minimize its drag in the water by reducing the cross-sectional area exposed to the flow while the whale is swimming. This is accomplished by using a 1.8 mm diameter stainless steel cable to connect the cylindrical housing and the penetration point. The cable is anchored to the anterior end of the cylindrical housing and the point shaft can slide up to 2 cm on the cable (Fig. lb). The point and cylindrical housing are rigidly joined during firing (Fig. la) to ensure penetration. When the shoulder of the cylindrical housing encounters the skin, penetration stops and the housing is pushed backward exposing the flexible cable between the point and housing. When deployed in this way the cylindrical housing lays flat on the skin and can rotate 360°. The flexibility and rotation allows the exposed housing to orient with the flow of water, thus reducing drag.

The radiotransmitter was designed and manufactured by Telonics, Inc. Frequencies selected were in the 150 MHz range, with individual radiotransmitters separated by 10 KHz increments. This separation prevents overlap and ensures proper identification of tagged animals. Crystals used were designed to withstand 196,000 $m/sec^2$ (20,000 g) of acceleration. Transmission pulse width averaged 14.6 ms and pulse rate 123 per minute.

Both high and low power transmitters were used. The range of the high power transmitter was greater, however, this is offset by approximately doubled power consumption. Using two lithium batteries rated at 1000 ma hours each, the theoretical life of the high power transmitter was about 2.5 months and of the low power transmitter about 5 months.

The two batteries were placed end to end in the anterior end of the cylindrical housing and the radiotransmitter in the rear. The two components were separated by a flange machined into the interior wall of the steel tube and by a friction-fit steel washer. These prevented displacement of the batteries into the radiotransmitter during acceleration yet allowed the batteries to be connected to the radiotransmitter through the center of the washer. The external antenna was joined to the transmitter by a feed-through connector soldered into a machined end cap. End caps were soldered to the cylindrical tube following placement of electrical components.

Where the whip antenna was attached to the end cap, epoxy was applied to strengthen the solder joint (Fig. 1). The antenna was then dipped into a liquid polyurethane resin (Conathane) which is a dielectric that is flexible after curing. The dielectric property was necessary to isolate the antenna from salt water and to maintain the flexibility required to coil it in the barrel of the darting gun.

Dart Gun

The gun used to project the radio-tag was a Mark 24 rifle manufactured by PAXARMS LTD. (Timaru, New Zealand). The barrel had an inside diameter of 1.892 cm. The charge was a 22-caliber blank cartridge chambered in a sliding bolt action. An adjustable valve between the chamber and the barrel adjusts the velocity of the projectile by releasing varying amounts of gas through the valve, thus varying the pressure behind the projectile. Desired velocity or range was selected by calibrating valve settings with projectile velocity during practice sessions. Noise from the gun's report is moderate, resembling that from the discharge of a 22-caliber short cartridge.

The radio-tag was loaded through the muzzle. A rubber O-ring was placed on the posterior end cap to form a seal between the tag and barrel . This concentrated pressure behind the tag and eliminated or greatly minimized bypass. The tag was pushed down into the barrel until the coiling antenna prevented further penetration. When seated in the barrel for firing the tip of the dart's penetrating point was about 1 cm from the muzzle.

Laboratory Testing

A piece of bowhead whale (Number 79B3) skin and blubber was obtained from Mr. Burton Rexford, a whaling captain in Barrow. It was used to test attachment devices for penetration and holding characteristics.

The maximum distance fired under test conditions was 9.1 m because this appeared to be the maximum distance that would be necessary to tag "friendly" gray whales in Mexico. A "friendly" whale is one that allows itself to be approached closely by boats or approaches boats on its own volition.

Prior to loading the radio-dart, whale oil extracted from blubber was applied to the posterior rubber O-ring. The oil both lubricated the tag during loading and firing and helped to seal the pressure from the charge behind the tag during firing. Various valve settings were tested during firing to obtain proper penetration into the skin and blubber tissue. Also, the tag was loaded in the barrel with the tip positioned at the top of the barrel and at three other positions, each rotated by 90°. Because the penetration point was off-center, it was important to determine whether the orientation of the point in the barrel influenced trajectory and penetration.

## Field Methods

Field tests took place in San Ignacio Lagoon, Baja, Mexico (Fig. 2). This lagoon is one of the important calving lagoons for the California gray whale. The field operation was in cooperation with the tagging project of Dr. Mate. His report, to which this report is appended, should be consulted for further details on the lagoon, field camp and logistic support (Mate 1980b).

Following receipt of the tagging permit from the Mexican government in January 1980, preparations were made to begin the tagging project. To test the ranges at which the radio-darts could be detected with the receiving equipment, representative high and low power radio-darts were placed in two Zodiac boats. One boat went north and one south into the lagoon. Tags were monitored from the base camp using two 5-element Yagi antennas on masts (later changed to 14-element Yagi's) and from a Cessna 182 aircraft with one H-antenna (Telonics, Inc.) mounted on each wing strut. Antennas were mounted parallel to the wing axis to increase lateral reception. Receivers used were Telonics Model TR-2 with scanners in the 150-152 MHz range. Photographs of antennas, antenna deployments,

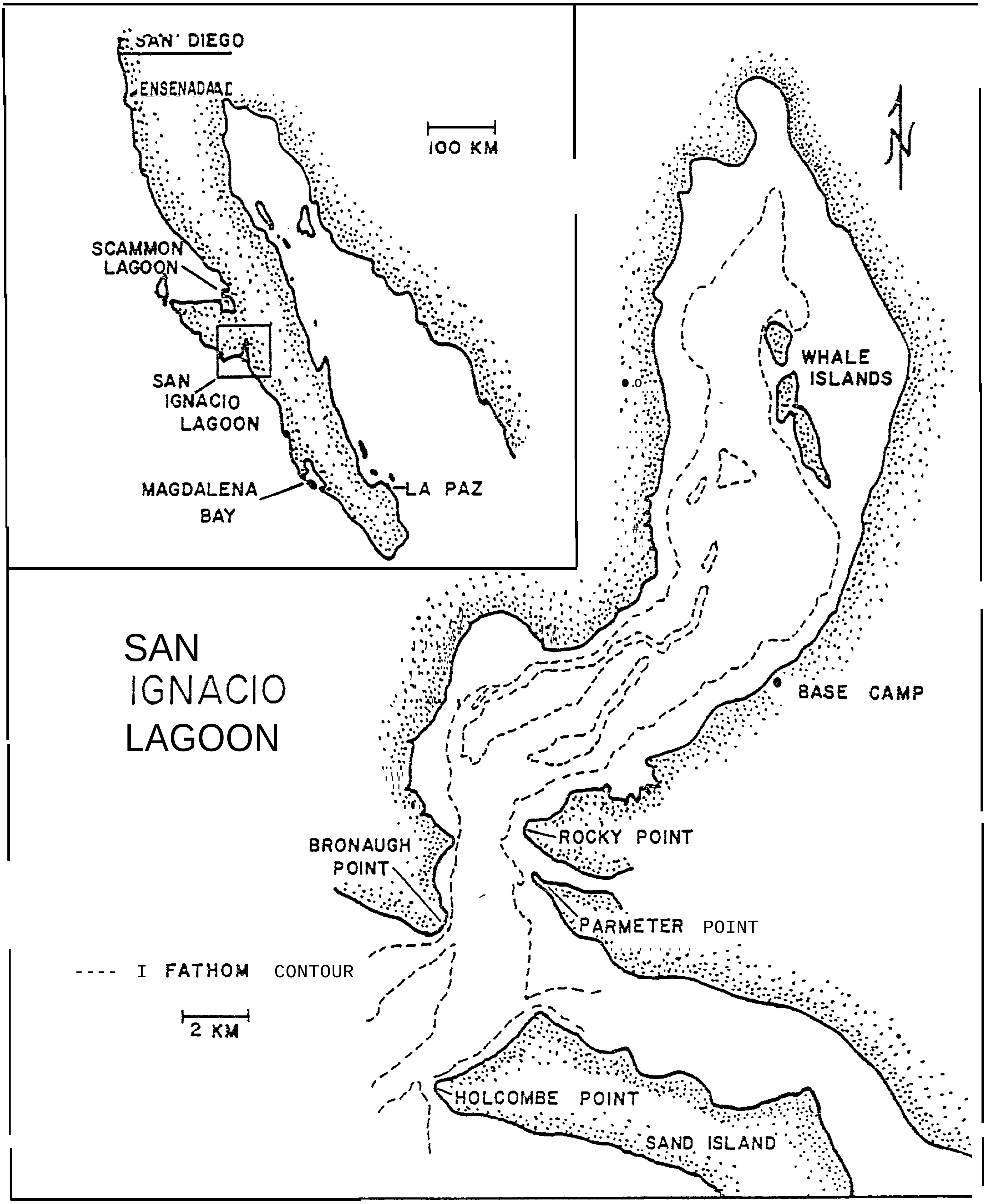


Figure 2. San Ignacio Lagoon, Baja, Mexico.

and receivers are included in the photo-documentation portion of the contract between Oregon State University and the Bureau of Land Management.

Following these tests, whale tagging began on 17 January and extended until 25 January. The tagging operation involved two Zodiac boats with three people per boat. The tagging boat attempted to approach whales in the lagoon while the backup boat maintained a distance from the tagging boat. The principal purpose of the backup boat was to aid in emergencies involving the tagging boat. It also had receiving equipment on board that was used to monitor whales after they were tagged.

Monitoring began on 18 January and continued until 1 March 1980. Monitoring from the base camp was accomplished with 14-element Yagi antennas on masts or with hand-held H-antennas. Monitoring from the air was accomplished using H-antennas and from boats using either a whip or H-antenna.

## RESULTS AND DISCUSSION

### Laboratory Testing

Testing of the radio-dart and darting gun were begun by firing only the cylindrical housing portion of the tag into a cardboard box. The housing was filled with weights to simulate the radio-dart's weight. This procedure permitted assessment of the power required to propel the dart, the gun's ability to handle the dart, and the dart's flight characteristics. These tests were conducted at a distance of 7.3 m. No problems were encountered in these tests although the dart tended to begin tumbling at the 7.3 m distance.

The complete radio-dart with electronic components was fired at a cardboard box several times to test it as above. Initial tests were made without the rubber O-ring on the rear end cap. Although the radio-tag performed well when loaded in this manner, it was thought that an O-ring would minimize pressure bypass and thereby provide more uniform results. The radio-tag maintained its horizontal orientation in flight and did not tumble out to 9.1 m. Also, the rifle was sufficiently accurate to allow consistent placement of the radio-dart within 5 cm of the target drawn on the box.

Following these tests the radio-dart was fired at a piece of whale skin and blubber to determine penetration characteristics and the power needed to penetrate the tissue. Settings of 12 and 14 on the gun's adjustable valve provided adequate penetration at 7.3 m and 9.1 m, respectively (Fig. 3). Good penetration occurred both when the skin was oriented vertically and when tilted at an angle to simulate the surface of a breaching whale. When the point of the radio-dart made contact at an angle less than 90°, it tended to rotate forward slightly thus forcing the penetration point into the tissue at an angle closer to 90° than the initial angle of contact. This minimized the possibility of the penetration point lodging just below the skin which could allow the toggled point to exit the skin near the shaft. Once the proper valve settings were determined for desired penetration (Figs. 3 and 4) the skin surface always pushed the cylindrical housing backward thus extending it at the end of the cable. In this position the cylindrical housing lays on the surface, as designed (Fig. 5).

After each firing the radio-tag was pulled backward. In all tests the toggle keyed as designed and prevented removal of the penetration point (Fig. 6). The point had to be cut out in order to remove it from the blubber.

The orientation of the radio-dart's point in the barrel was important to ensure proper penetration. For positive penetration each time, it was necessary to load the radio-dart so that the off-center penetration point was at the top of the gun barrel. Upon making contact with the skin the forward rotation of the tag was in the same direction as the rotation of the penetration point on the hinge thus holding it rigid against the shaft for full penetration. When the radio-dart was loaded with the penetration point at the bottom of the barrel, the rotation of the tag on contact opened the toggling point and caused it to penetrate only partially or to cartwheel off the skin. The rubber O-ring is not strong enough to hold the penetration point rigid during penetration in this orientation. Since the radio-dart did not spin in the barrel or in flight, maintaining proper orientation of the dart was not a problem.

The radio-dart was very durable. The crystal designed to withstand 196,000 $m/sec^2$ of acceleration, was more than adequate to withstand any

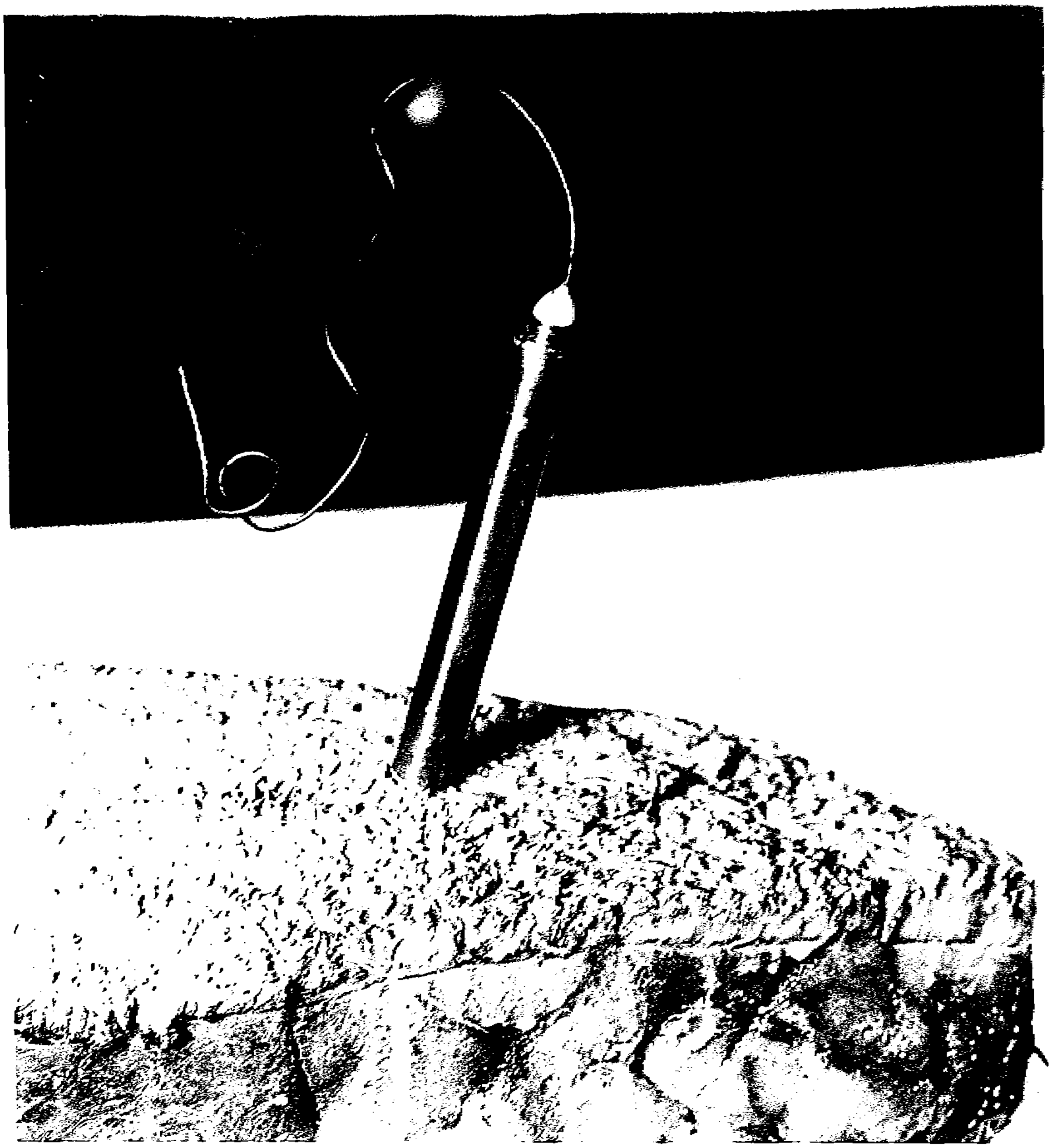

Figure 3. Radio-dart stuck in test block of bowhead whale skin and blubber. This depicts maximum desired penetration.

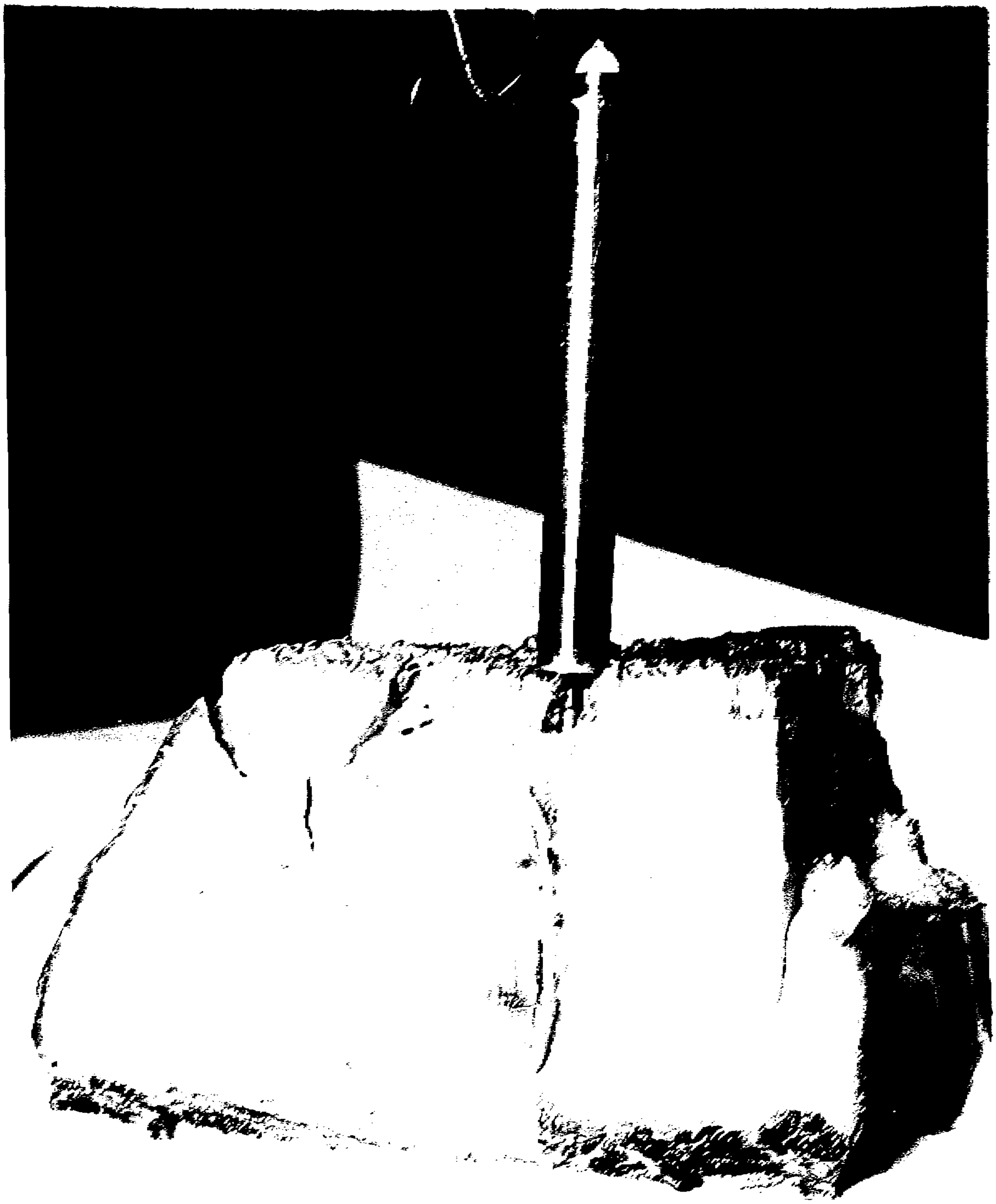

Figure 4. Attachment point of radio-dart embedded in test block of bowhead whale skin and blubber. This depicts maximum desired penetration and represents the deployment after firing, before the hinged penetration point begins to deploy laterally in the blubber.

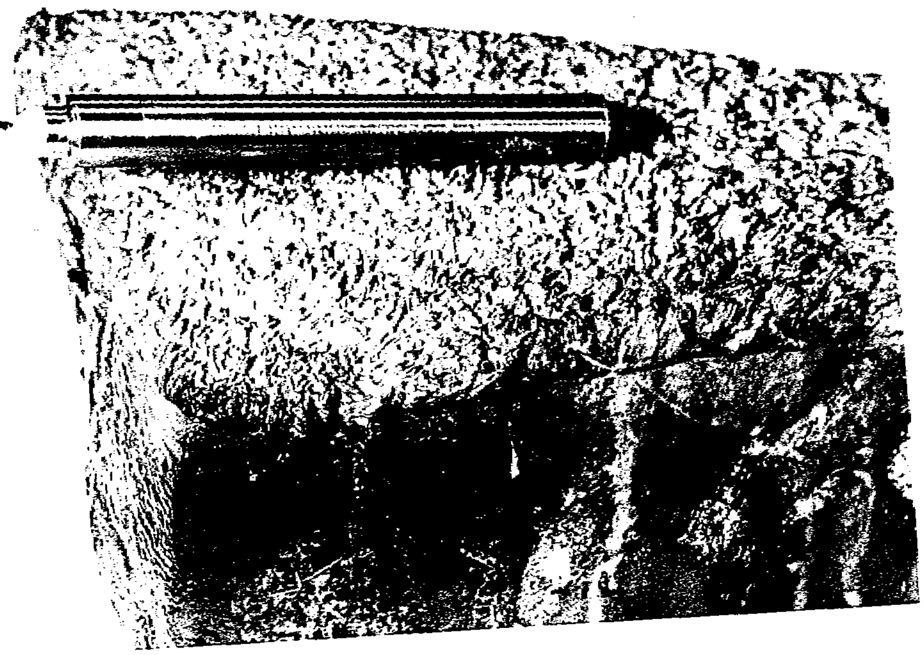

Figure 5. Radio-dart deployed horizontally on the surface of bowhead whale skin. This depicts the orientation of the cylindrical housing and antenna on the surface of a whale.

Figure 6. Attachment point of a radio-dart with the hinged penetration point deployed laterally in the blubber of a block of bowhead whale tissue.

abuse the tag would be subjected to during firing, or on a whale. One shot that deflected off of the skin during testing caused the radio-dart to hit a wall and fall on the floor. The severity of the impact caused the front end cap to dislodge and expose the batteries, but the transmitter was still operating. No such trauma would be encountered during a field tagging operation. It was never necessary to fire the tag at a valve setting greater than 15, but it is doubtful that the acceleration in the barrel at even the highest setting would be enough to cause any damage to the radio-tag's components.

Field Testing

Results of the on-water tests of the low and high power radio-darts were inconclusive because of equipment problems with the land-based 5-element Yagi antennas. Antenna connectors were not working properly and the antenna gain was greatly reduced. Using one Yagi antenna at a time or a hand-held H-antenna, both low and high power radio-tags were received at a distance of up to 10.- km. From the aircraft both of the high power and one of the low power radio-tags were received at a distance of about 64 km. These results were considered satisfactory if similar ranges could be achieved from tagged whales.

Whale Tagging

Nine attempts were made to tag gray whales in San Ignacio Lagoon between 17 and 25 January 1980 (Table 1). Radio-tags were successfully placed on two whales. Other tags either fell short or went beyond the whale.

Successful Attachments. Radio-dart #8 was placed on a large gray whale on 18 January (Table 1). The tag entered the skin on the left side about 1 m below the dorsal midline and about 2.5 m posterior to the blowhole. The radio-dart entered the skin at about a 30° angle since the whale was about one boat length forward of the starboard bow when tagged. The tag entered up to the shoulder of the cylindrical housing as designed. The whale was followed for 25 minutes through choppy water

Table 1. Radio-tag specifications and disposition during a gray whale tagging experiment in San Ignacio Lagoon, Baja, Mexico; 1980.

| Transmitter | | | | |
|---|---|---|---|---|
| No. | Frequency(MH$_z$) | Power | Date | Disposition |
| 1 | 150.030 | Low | 1/20 | On whale |
| 2 | 150.040 | Low | 1/20 | Fell short |
| 3 | 150.060 | Low | ---- | Not fired |
| 4 | 150.070 | High | 1/24 | Fell to side |
| 5 | 160.080 | High | 1/24 | Skipped off whale |
| 6 | 150.090 | High | 1/17 | Fell short |
| 7 | 150.100 | High | 1/24 | Fell short |
| 8 | 150.110 | High | 1/18 | On whale |
| 9 | 150.130 | High | 1/21 | Fell short |
| 10 | 150.150 | High | 1/25 | Skipped off whale |

and the tag was observed in place four separate times, suspended downward from the point of attachment by the short cable joining the cylindrical housing with the penetration point. The device was deployed exactly as designed.

During pursuit of this whale no radio signals were received by the backup boat and, in fact, no signals were ever received from this tag. The location of the radio-dart on the whale was undoubtedly the cause of this problem. When the radio-dart was observed on the swimming whale only the cylindrical housing and, at times, a portion of the proximal end of the whip antenna was above the water line. The majority or all of the antenna was trailing in the water. Salt water severely attenuates radio signals and this probably accounted for the lack of signal reception even from a nearby boat (100+ m). The only time that signals would be transmitted was if the animal rolled on the surface thus exposing all or most of the whip antenna. Without retrieving the radio-dart, damage to the transmitter cannot be ruled out as a causative factor; however, the results of laboratory tests make it seem unlikely.

Conclusions reached from this first tagging effort were clear. Although the exposed surface of an adult gray whale is quite large, it is essential that the radio-dart, as designed, be placed as near as possible to the dorsal midline. Thus, when deployed, the entire cylindrical housing and all or most of the whip antenna would be above the water line when the whale is surfaced to breathe. The combined length of the cylindrical housing and whip antenna is 0.61 m. Proper placement of the tag should be approximately within 0.5 m of the dorsal midline of an adult-sized gray whale to ensure sufficient exposure of the antenna when a whale is surfaced.

Radio-dart #1 was placed on a large gray whale on 20 January (Table 1). The tag entered the skin on the left side approximately 0.5 m below the dorsal midline and about 2 m posterior to the blowhole. Entry was at about a 45° angle. Deployment of the radio-dart on the whale was as described for #8 above. The higher position on the side of the whale exposed all or most of the tag when the whale was surfaced to breathe.

This whale was followed in the backup boat for about 1 hour following tagging and the radio-tag functioned well. Because engine static prevented reception, the boat was periodically shut down to listen to the transmitter and then started up to approach the whale again. Following a brief stop in tracking efforts contact was again made with the whale using the radio signal. Contact was continued until about 5 hours after the whale was initially tagged. During this period the whale remained in the lagoon (Fig. 7). Maximum signal reception from the boat was about 11.5 km. No signals from this whale were received at the field camp on the day of tagging, however, at this time the 5-element Yagi antennas which posed problems during the on-water tests were still in use.

The signal from whale #1 was not received from either the backup boat or the shore-based receivers on 21 January nor from the shore-based receiver on 22 January. On 23 January signals were received from whale #1 at the field camp. Signals, in groups of 6 to 10 pulses, were heard beginning at 1045 and lasting about 4 minutes. The signal was weak suggesting that the whale was at extreme reception range but the water was too rough to verify its position using a boat. This was the last positive reception of this whale's transmitter, 72 hours after it was tagged.

On 8 February an observer thought that a signal was heard with a land-based H-antenna on the frequency of whale #1's transmitter. Apparently the pattern of beats and the sound were similar to other radio-tags that this observer had heard. Also, the beats occurred in groups of 3 to 4 and about 4 to 5 groups were heard over a period of about 1 minute. This pattern reflects the behavior of a whale alternately surfacing and submerging. The signals apparently did not gradually fade in or fade out which would appear suspicious to one inexperienced in monitoring radio-tags. A transmitter at maximum range would not necessarily provide this signal variation. It would either be heard or not heard. Varying orientation of the antennas did not improve the signal, thereby suggesting that the transmitter, if it was the whale, was exposed in front of the antenna at maximum range. Since this event occurred at Rocky Point, close to the lagoon's mouth, it is probable that the whale was beyond the mouth in the offshore area. This remains speculation because the observer was not confident in what was heard.

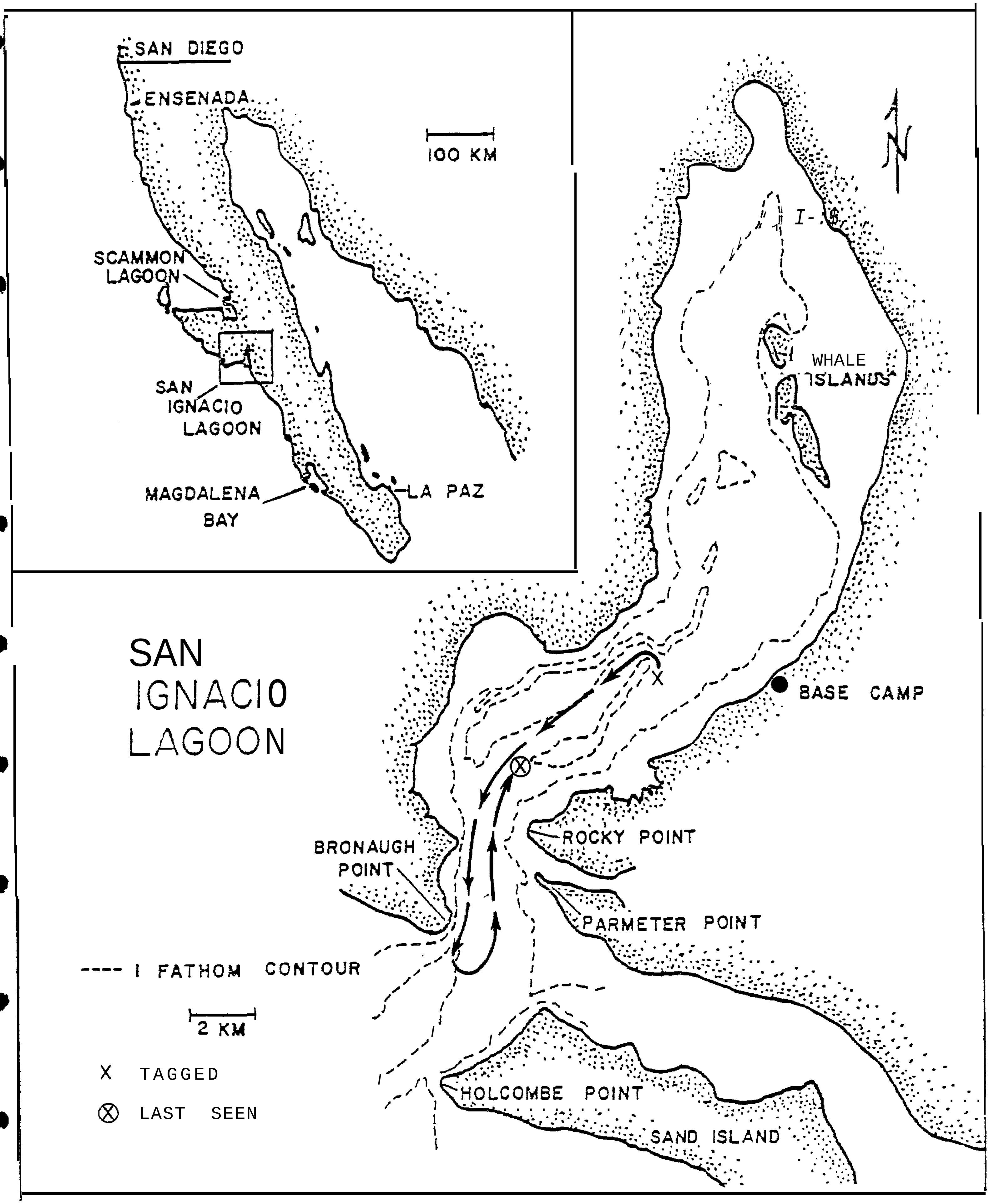


Figure 7. Path of gray whale radio-tagged on 20 January, 1980 and followed by boat for about 5 hours.

If it was the instrumented whale, this would represent 20 days since tagging. An aerial survey in the area on 9 February did not detect any signals of the appropriate frequency.

Several locations and antenna systems were used to monitor for the whales after these two were tagged. Most of the time (61%) was spent at base camp using 14-element yagi antennas, one aimed north to cover the upper part of the lagoon and the other aimed southwest to cover the mouth of the lagoon. A large portion (33%) of the monitoring was from a 6 m tower at Rocky Point using a hand-held H-antenna. The H-antenna was also used from the ground at Bronough Point a few times, while a whip antenna was used to monitor from a boat on the water. Some surveys were flown in the Cessna 182 to attempt to locate the whales from the air. In addition, the left side of all whales that could be observed was inspected for radio-darts that might be present but not functioning.

The monitoring effort through 1 March 1980 is depicted in Figure 8. Occasionally, simultaneous monitoring was conducted from different locations. A breakdown of the number of minutes spent monitoring each day and from what locations is presented in Table 2. The overall average was 4.6 hours per day. This figure includes five days with no monitoring, but it does not include estimates of the hours spent monitoring by Dr. Mate on various flights he made along the coast. A summary of the aerial monitoring effort through 1 March is presented in Table 3. It should be noted that unless two people were aboard the aircraft it was impossible to listen continuously for both the radio-darts and Mate's tags because the different frequency ranges required separate receivers. Thus, times identified represent the entire flight not the time spent listening for the radio-darts.

The monitoring was a simple though time-consuming effort and there were few difficulties. There was a certain amount of noise that could occasionally be mistaken for a signal. In addition, ignition noise from the outboard motors was loud enough to prevent monitoring from the boats with the motor running, and even from land if a boat was directly in line and within 300 m of the antenna. These problems were minor and did not significantly affect monitoring for the tagged whales.

No signals from radio-tagged whales were recorded during the monitoring effort except those on 20 and 23 January and the possible

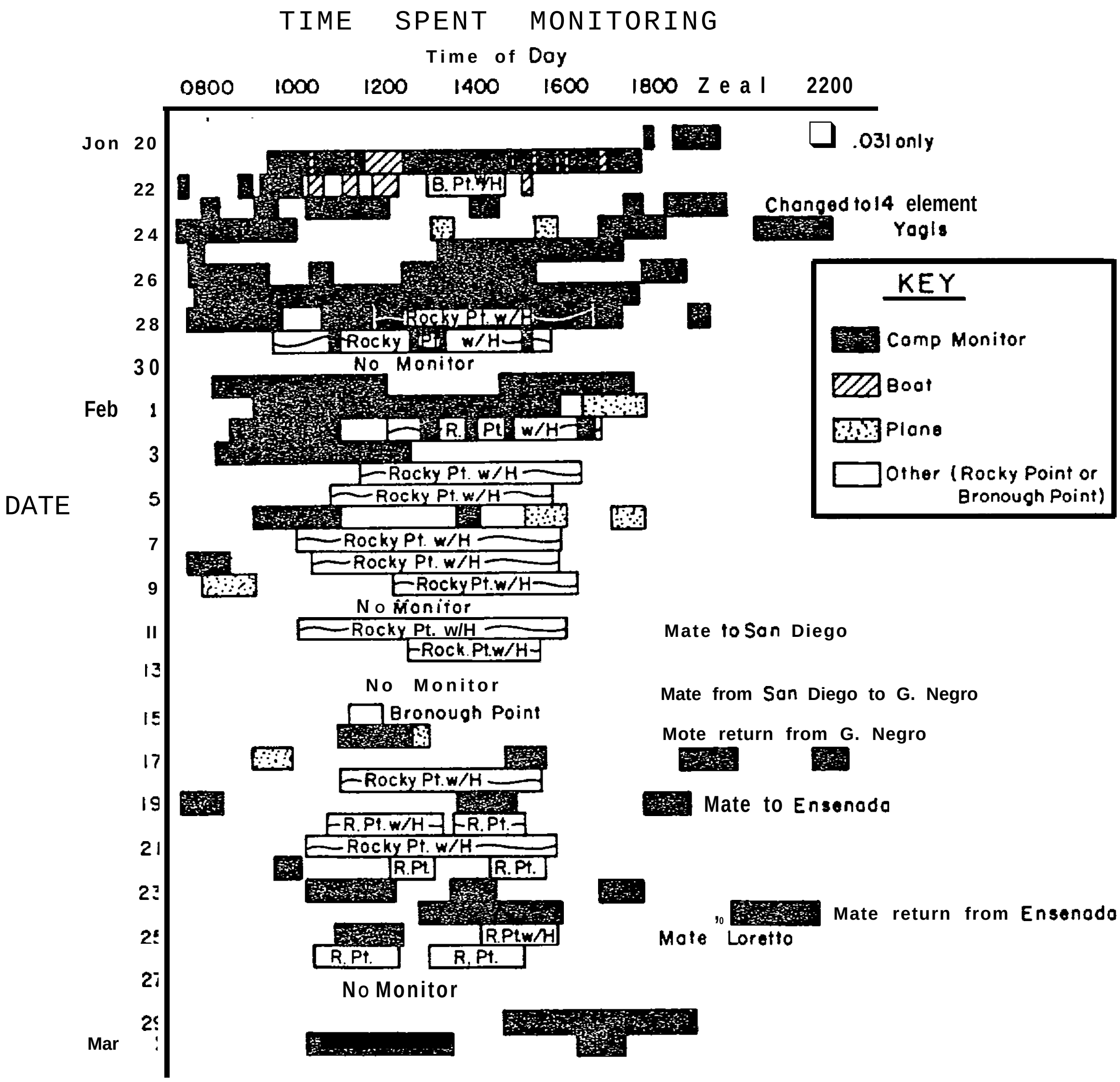


Figure 8. Monitoring schedule for tagged gray whales, San Ignacio Lagoon, Baja, Mexico.

Table 2. Distribution of time spent monitoring for radio-tagged gray whales, San Ignacio Lagoon, Mexico, 1980.

| Date | Minutes Spent Monitoring | | | | | |
|---|---|---|---|---|---|---|
| | Base Camp | Rocky Point Tower | Bronough Point | Airplane | Boat On The Water | Total |
| Jan 20 | 104 | --- | --- | --- | --- | 104 |
| 21 | 502 | --- | --- | --- | 115 | 617 |
| 22 | 90 | --- | 105 | --- | 82 | 277 |
| 23 | 311 | --- | --- | --- | --- | 311 |
| 24 | 359 | --- | --- | 60 | --- | 419 |
| 25 | 272 | --- | --- | --- | --- | 272 |
| 26 | 380 | --- | --- | --- | --- | 380 |
| 27 | 597 | --- | --- | --- | --- | 597 |
| 28 | 562 | 285 | --- | --- | --- | 847 |
| 29 | 74 | 375 | --- | --- | --- | 449 |
| 30 | --- | --- | --- | --- | --- | --- |
| 31 | 420 | --- | --- | --- | --- | 420 |
| Feb 1 | 415 | --- | --- | 90 | --- | 505 |
| 2 | 207 | 290 | --- | --- | --- | 497 |
| 3 | 265 | --- | --- | --- | --- | 265 |
| 4 | --- | 300 | --- | --- | --- | 300 |
| 5 | --- | 300 | --- | --- | --- | 300 |
| 6 | 152 | --- | --- | 100 | --- | 252 |
| 7 | --- | 360 | --- | --- | --- | 360 |
| 8 | 60 | 335 | --- | --- | --- | 395 |
| 9 | 250 | --- | --- | 75 | --- | 325 |
| 10 | --- | --- | --- | --- | --- | --- |
| 11 | 365 | --- | --- | Mate to S.D. | --- | 365 |
| 12 | --- | 180 | --- | --- | --- | 180 |
| 13 | --- | --- | --- | --- | --- | --- |
| 14 | --- | --- | --- | Mate from S.D. | --- | --- |
| 15 | --- | --- | 45 | --- | --- | 45 |
| 16 | 124 | --- | --- | 25 | --- | 149 |
| | | | | Mate from G. Negro | | |
| 17 | 90 | --- | --- | 55 | --- | 145 |
| 18 | --- | 272 | --- | --- | --- | 272 |
| 19 | 200 | --- | --- | Mate to Ensenada | --- | 200 |
| 20 | --- | 255 | --- | --- | --- | 255 |
| 21 | --- | 340 | --- | --- | --- | 340 |
| 22 | 38 | 135 | --- | --- | --- | 173 |
| 23 | 241 | --- | --- | --- | --- | 241 |
| 24 | 312 | --- | --- | Mate from Ensenada | --- | 312 |
| 25 | 92 | 105 | --- | Mate to Loreto | --- | 197 |
| 26 | --- | 243 | --- | --- | --- | 243 |
| 27 | --- | --- | --- | --- | --- | --- |
| 28 | --- | --- | --- | --- | --- | --- |
| 29 | 261 | --- | --- | --- | --- | 261 |
| March 1 | 264 | --- | --- | --- | --- | 264 |
| Total | 7,007 | 3,775 | 150 | 405 | 197 | 11,534 |
| Percent | 61 | 33 | 1 | 4 | 1 | 100 |

Table 3. Summary of flights taken to monitor radio-tagged gray whales, Baja, Mexico; 1980.

| Date | Duration (min.) | Route of Flight |
|---|---|---|
| 24 Jan | 60 | From camp to mouth of the lagoon then to Campo Renee (-16 km up the coast). Return by same route. |
| 1 Feb | 90 | Four trips of about 20 minutes each. They went from camp to the mouth of the lagoon and back. |
| 6 Feb | 100 | Flew from camp to mouth of lagoon and then directly to Guerrero Negro. Return trip was the same except went around the north end of the lagoon. |
| 9 Feb | 75 | Flew to the lagoon mouth and to 13 km off-shore, then to Campo Renee. Returned to camp via the mouth of the lagoon. |
| 11 Feb | 120+ | Flew along coast to San Diego. Monitored until San Quintin. |
| 14 Feb | 60+ | Flew to 1 hour north of Guerrero Negro. Monitored on way north. |
| 16 Feb | 85+ | Monitored on return from Guerrero Negro. Also, spent 25 minutes on Alaska frequencies off the mouth of the lagoon. |
| 17 Feb | 55 | Flew to mouth then out to sea for -24 km. Made a left turn and flew 16 km south, then turned toward the coast. Flew north along the coast then to camp. |
| 19 Feb | 90+ | Monitored on flight to Ensenada. |
| 24 Feb | 120+ | Monitored on return from San Diego. |
| 25 Feb | 30+ | Flew south along the coast to the latitude of Loreto. |

contacts heard on 8 February. The monitoring program was sufficiently consistent and thorough that it is likely that if any of the tagged whales were in the area with functioning transmitters, they probably would have been detected. None of the whales observed closely from boats during February through April had radio-darts on them. Therefore, the only possible explanations for not detecting at least whale #1 are that the radio-tags fell off and/or stopped operating or that the whales left the area, perhaps starting their northward migration early. Both whales were without calves at the time of tagging. Single whales probably have less long-term attraction to the lagoon during these months than pregnant whales or ones with calves.

Unsuccessful Tagging Attempts. In addition to the two successful tagging attempts, seven other attempts were made (Table 1). In these instances tags either fell short or went beyond the whales. Problems encountered were several, the most significant being the lack of "friendly" whales in the lagoon during the mid-January tagging program and a technical problem with the tagging equipment.

The tagging experiment was planned to take advantage of the "friendly" whales that annually frequent San Ignacio Lagoon during winter. During the period of tagging no such whales were encountered and, in fact, the whales present had to be pursued in most cases in order to approach sufficiently close to attempt placement of a tag. During the tagging period through 25 January, three boat surveys were conducted on the lagoon yielding an average of 94 whales in the lagoon' (S. Swartz, personal communication to G. Miller, 1980). The average number of whales observed on three boat surveys during the first two weeks of February had already increased to 200 (op. cit.) and the numbers probably increased for several weeks thereafter. Similarly, the number of "friendly" whales increased over this period. The minimal number of whales and the lack of "friendlier" during the January tagging effort decreased the tagging success. This would have been less a factor had the preparation for field work not assumed the presence of approachable whales. Placing a tag on a large relatively stationary target is easier than on a passing whale whose location near the boat can only be determined seconds before the radio-dart must be fired. Although these may be the usual conditions for tagging whales they were not expected for this experiment which was designed to determine the performance of the radio-dart on a whale. The experiment did show, however, that the tagging system described here can be used to tag whales under adverse conditions and in all directions around the boat except over the stern where the boat's operator is positioned. Successful tagging under these conditions relies heavily on the snap-shooting skill of the tagger.

Besides the two successfully tagged whales, three other attempts were made to tag whales through 21 January. All three of these radio-darts fell short of the whale. Two of these attempts were made at whales at a distance approaching 14 m. The size of the surfacing whale contributed greatly to the illusion that the whale was closer than it really was. In one case, the radio-dart fell short by about 0.3 m but hit the whale. This whale was followed to determine whether the tag had penetrated the skin. The tag was not observed thus indicating that 0.3 m of water sufficiently decelerates the radio-dart to prevent penetration. Had the whale been successfully tagged radio signals would not have been received because the antenna would have trailed in the water.

The radio-darts which fell short, even those fired at whales beyond the desired range, fell shorter than would have been expected based on the laboratory experiments. This was also the case for the two radio-darts that were successfully placed on whales. The trajectory was greater than in the tests which indicated a technical problem with the equipment. Before any more tagging attempts were made, the problem was identified and rectified.

Greater than normal friction of the radio-darts in the barrel changed the trajectory of the radio-dart and caused the tag to fall short of the whale. Radio-darts were lubricated with rendered whale oil during testing whereas in the field silicone grease was used because of its convenience. Although the silicone grease functioned well under test conditions, in the field it appeared to contribute to the additional drag experienced when loading the barrel. This could have been due to the generally lower ambient temperatures in the field. However, the time between loading the radio-dart and firing it, sometimes overnight, may have allowed the grease to set or congeal thus increasing drag during firing. The use of Wesson Oil partially solved this problem because its lower viscosity maintained the proper lubrication even after extended periods between loading and firing.

The Wesson Oil did not solve the problem completely, however. Even with its use more drag was experienced than when tests were conducted. Inspection of the rubber O-rings which fit over the rear end cap revealed that the inside diameters varied slightly but generally were less than for the two which were used on the test radio-darts. This variation caused the outer edge of the O-ring to be forced more tightly against the inside of the barrel, thereby increasing the friction. The insides of the O-rings on the remaining darts were scraped with knives to increase the inside diameter thus alleviating the problem. This procedure in combination with use of the less viscous Wesson Oil completely solved the problem and the four subsequently fired radio-darts functioned properly, as during the tests.

Two radio-darts fired after the technical problem was solved hit the targeted whales but skipped off. In one case the aim was high and the side of the tag hit the top of the whale and glanced off. In the other a mistake was made in loading the radio-dart. The tag was loaded with the penetration point rotated 180° so that it was at the bottom of the barrel. When the tag hit the whale high on its side it cart-wheeled off just as was found during tests using the block of bowhead tissue.

The two other tagging attempts reflected poor aim. One tag fell just to the side of a whale as it surfaced parallel to and ahead of the boat. The other fell about 0.5 m short just as the whale was submerging. In neither case could altered trajectory due to the increased friction problem be considered the causative factor for the misses. The tenth radio-dart was not Fired because tests indicated a decreased power output.

## Reaction of Whales

Neither the tagged nor the missed whales reacted violently *to* the radio-dart. The typical reaction was to submerge quickly usually causing a large boil of water as the flukes were drawn close to the surface. The first whale tagged was swimming with three others and remained with this group for at least 25 minutes after tagging, when our contact with the whales was broken. The second whale tagged was also with three others. A few minutes after it was tagged it broke off from the group and swam down the lagoon where it joined up with another whale.

Missed whales reacted similarly. They usually submerged quickly, causing a large boil. Whether the whales reacted to the contact of the radio-dart or to the sound is unclear because in at least one case an adult whale next to the target whale reacted similarly even though it was never contacted by the tag.

Since none of the whales tagged or pursued were "friendly" it could not be determined whether they would again approach the tag boat after darting, as was the case during the previous year's tagging experiment. However, because their reaction to the radio-dart was similar to the whales instrumented with the umbrella tag, it could be speculated that they would not be deterred from continuing their "friendly" behavior.

## CONCLUSIONS

The fact that only two of nine whales were successfully tagged with the new design radio-dart does not indicate a flaw with the design or attachment procedure, but rather reflects on the skill of the tagger in hitting pursued whales. The radio-dart design and tagging system were quite satisfactory once the lubrication problem was solved. Some design changes should be initiated prior to further use of the radio-darts on whales.

A summary of major conclusions of this project follow:

1. The radio-dart as designed performs extremely well with regard to its flight characteristics and penetration. The components as situated provide excellent in-flight balance which prevents tumbling and spinning. The mechanism to allow the cylindrical housing to lay on the skin worked on every test firing and on the two tagged whales. The hinged penetration point deployed laterally, as designed, during each test firing, when an

attempt was made to remove the tag from the block of whale blubber. The angle of penetration can be acute, at least 30°, which allows great flexibility in placing the radio-dart from various locations around the whale.

2. The range of reception from an aircraft for both the low- and high-power radio-darts was very good under test conditons, achieving about 64 km.
3. The radio-dart will not penetrate the skin if it passes through water before striking the whale.
4. The reaction of the whales to tagging is minimal and may be more in response to the sound of the discharge than the contact of the tag.
5. The major advantage of this tagging system is its utility for tagging whales that are not closely approachable. Of the 7 days actually spent attempting to tag whales, radio-darts were fired on 6 days. On only one day was there a problem approaching whales within the desired 9.1 m. In essence this radio-tagging system permitted instrumenting whales virtually whenever the water was sufficiently calm to allow standing in the boat. Not having to depend on approachable whales is a significant consideration when selecting a tagging system for large whales, especially species other than the gray whale.
6. As designed, the radio-dart must be placed high on the side of a whale to ensure exposure of the trailing whip antenna when the whale surfaces to breathe. The design of the radio-dart should be modified to either shorten the antenna, alter its configuration, or relocate it to the front of the cylindrical housing. Either approach would enlarge the potential target area on the side of a whale.

## ACKNOWLEDGEMENTS

The creative abilities and machining talents of Mr. A. E. (Ned) Manning are gratefully acknowledged. His assistance and guidance during all phases of the project contributed greatly to the successes achieved.

Mr. Dave Beaty of Telonics, Inc. provided invaluable assistance and advice in adapting the radio-transmitter to the dart housing. The support of Dr. Bruce Mate and his assistants, particularly Mr. Jim Harvey, made the field effort in Mexico possible. Sharing the camp facility and working with this group made for a very pleasant and enjoyable experience. Mr. Steve Swartz and Ms. Mary Lou Jones graciously allowed us to use their camp and observation tower at Rocky Point. The continued interest of Mr. Jerry Imm of the Bureau of Land Management in supporting development of the radio-dart and subsequent testing is gratefully acknowledged. Finally, we wish to thank all those who contributed to this project by sharing experiences with marine mammals and providing advice and criticism of the work. Those whom we wish to acknowledge in particular are Mr. Larry Hobbs of the Marine Mammal Tagging Office and Mr. John Burns of the Alaska Department of Fish and Game.

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