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POPULATION STUDIES OF KILLER WHALES (ORCINUS ORCA) IN THE PACIFIC NORTHWEST: A RADIO-MARKING AND TRACKING STUDY OF KILLER WHALES

ALBERT W. ERICKSON

MARINE MAMMAL COMMISSION
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A RADIO-MARKING AND TRACKING STUDY OF KILLER WHALES

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The views and ideas expressed in this report are those of the author. They are not necessarily shared by the Marine Mammal Commission or its Committee of Scientific Advisors on Marine Mammals.

ABSTRACT

This study reports (1) the development of a radio transmitter suitable for tracking killer whales and the results of an effort to track two radio-marked killer whales over a period of five months, and (2) the results of a limited photographic identification study of killer whales in Puget Sound.

The procedural steps employed in the development of a radio-marking technology for killer whales included (1) studies of the morphology and anatomy of the fin of the killer whale (2) the development and testing of prototype radios, and (3) the development of a method for attaching radio-transmitters to killer whales.

The radios ultimately developed weighted 3.1 pounds, and were capable of surface and aerial monitoring to distances of 5 and 18 miles, respectively. The radios were affixed to the anterior base of the dorsal fin by four surgical pins set just beneath the skin. The radio pack was designed to self-release after the one-year life of the transmitters by timed corrosion of the nuts securing the radio packs to the whales.

Tests of the radio technology developed included an initial continuous ten-day tracking effort during which the whales traveled extensively throughout upper Puget Sound and Georgia Straits. The daily travel distance of the whales averaged 68 nautical miles and the average travel speed was 2.8 nautical or 3.2 statute miles per hour. Maximum measured speeds for short distances approximated 16 nautical miles per hour. The mean dive cycle of the whales was 5.77 minutes. The cycle consisted of a long dive followed by three or four surface blows of 3 or 4 seconds spaced a mean 21 seconds apart. The longest recorded dive of 1365 timings was 17 minutes. Periodic observations and signals of the whales were received over a five month period following the release of the whales. These results suggest that a base technology is in hand for radio-marking studies of killer whales. Conceivably the same technology could be employed in radio-marking studies of other cetaceans.

The limited photo identification study permitted the identification and characterization of "J" pod, a resident pod of killer whales. The pod composition was the same as documentated in a study conducted by the National Marine Fisheries Service in 1976. Namely, 3 adult bulls, eight adult cows and 5 calves. One of the calves had been born since the October termination of the National Marine Fisheries study and another had apparently been lost from the pod.

ACKNOWLEDGEMENTS

I should like to express my great appreciation to the many agencies and persons who contributed to the successful execution of the killer whale studies reported here.

Particular thanks are due the Marine Mammal Commission and Sea World, Inc. for providing the material resources necessary for carrying out the investigations. Persons deserving special thanks include Messers. Larry Kuechle and Richard Reichle of the University of Minnesota, Cedar Creek Electronics Laboratory for their forebearance in the development of the radio transmitters used on the whales, and Drs. Lanny Cornell and Tag Gornall and Mr. Donald Goldsberry of Sea World, Inc. for the many assistances rendered in connection with the capture, handling and curating of the whales while in captivity and assisting generally in the research studies.

Other persons contributing materially to the research effort include Dr. Colin Sandwith of the University of Washington's Applied Physics Laboratory for assistance rendered in the development of the corrisible release mechanism; Dr. Theodore Greenlee of the University of Washington's Medical School for advise and assistance in the development of procedures for attaching transmitters to the whales, and Mr. James Johnson of the Marine Mammal Laboratory of the National Marine Fisheries Service for his help in pressure testing transmitters and as a most capable and congenial team member during the initial ten-day radio tracking effort.

I should also like to thank Mr. Al Bruce, Skipper of the tracking vessel Propeller for the many services rendered in readying gear and crew in the radio-tracking effort. I am additionally grateful to the many persons who voluntarily served as guards and field assistants during the period the whales were retained as captives or research subjects. Special thanks are also due student aids Brad Hanson and Jeff Foster for their enthusiastic and capable assistance throughout the project.

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Introduction

This report presents the results of a study to develop technology for radio-marking and monitoring the movements of killer whales, and to conduct a field test of the technology. The study was performed under Marine Mammal Commission contract number MM5AC012 awarded to the author on 11 April 1975 and supplementally extended and amended on August 12, 1976. The studies were extended to permit continued monitoring of two radio-marked killer whales, and to analyze data obtained during the tracking effort.

In addition to the grant funds provided to the project by the Marine Mammal Commission, substantial financial, material and logistic support was contributed to the project by Sea World, Inc. The period of the investigations extended from 11 April 1975 to June 30, 1977.

Methods

The procedures employed in the development of the radio-marking effort reported here concerned a regime of activities designed to assess the efficacy of the procedures to be employed prior to the use of the procedures in the field. These procedures included reliability tests of the equipment developed and controlled studies of radio-marked whales prior to their release.

As a first step in designing a radio-pack for the killer whale a fin cast (Figure 1) was taken of "Sandy" a 21-foot female killer whale retained as a research animal in San Diego by Sea World. Following this a radio transmitter and attachment harness was designed to be affixed to the anterior base of the dorsal fin of a whale.

The basic criteria sought in the development of the radio-pack were (1) a minimum transmission life of one year, (2) a signal distance approximating the 20 airline miles achieved with transmitters placed on large terrestrial mammals, and (3) a radio package which would not annoy the whale or cause behavioral aberrations.

The basic radio telemetry system selected for fabrication was the system developed by Messers. Larry Kuechle and Richard Reichle of the Cedar Creek Electronics Laboratory of the University of Minnesota. This system has been adapted to a wide variety of bird and mammal studies, including seals and sea otters. The specifications and circuitry of the transmitters is presented as Appendix 1.

The transmitters configured for use on killer whales were powered with two 2.8 volt lithuim batteries generating a power output of approximately 10 millowatts. The transmitters operated in the 164-165 MHz range and were pulsed at a rate of 100 beats per minute to achieve lengthed battery life and to permit greater signal identification. The antenna was a whip antenna constructed of a 17 inch length of vinyl coated 8/32" stainless steel cable reinforced at the base with a six inch length of rubber hose.

Figure 1. Making a plaster fin cast of a killer whale.

The first radio unit developed was potted with 3M Scotchcase #5 electrical resin in an eight-inch length of 2-1/2 inch diameter stainless steel tubing and with the harness pack weighed five pounds. Subsequent, packs of the design illustrated in Figure 2 were reduced to 3.1 pounds in weight by potting the radios in 2 inch diameter thin gauge aluminum or plastic tubing.

The harness for the attachment of the radio to the dorsal fin of a whale was constructed of two layers of 6-inch wide PVK 120 single ply polyester/polyvinyl belting. This was pop-riveted to the radio housing tube prior to potting as illustrated in Figure 2. The inner surface of the harness was lined with a 3/16" thick layer of neoprene sponge where the pack would lie against the skin of an instrumented whale.

Once the prototype pack had been developed the entire radio package was submitted to a series of reliability and performance tests. Distance checks of the radio from a small boat and from a light aircraft and utilizing Yagi antennas yielded line of sight surface ranges of approximately five miles and air ranges up to 18 miles with the transmitter located at the water surface. The transmitter was subsequently placed in an ocean water tank at the Seattle Marine Aquarium for 30 days and its operation was periodically confirmed. Following this the transmitter was placed in a water pressure tank and submitted to 1,000 PSI of pressure for a period of 30 minutes. This pressure was equivalent to a sea depth pressure of over 1,000 ft. and well in excess of the maximum 850 foot known recorded diving depth of killer whales (Bowers and Henderson, 1972).

Following these tests the radio was still functioning normally. However, the radio ceased operation two days following the pressure test. Upon examination it was determined that one of the rivets used to attach the belted harness to the radio had been forced through a thin area of the potting acrylic in which the radio components were housed. While this fracture was minute it was nonetheless sufficient to allow water invasion which caused radio failure. This problem was avoided in later generation radios by placing the harness rivets at the ends of the housing tube and away from the radio components. All additional radios including one of two transmitters actually placed on killer whales withstood the water pressure test.

The procedure devised for attaching radio packs to the dorsal fins of killer whales was by the use of several 5/32" diameter stainless steel self-threading surgical pins. These pins were to be set shallowly below the surface of the skin to avoid the internal integrity of the fin. The nuts to be used to secure the pack to the whales were corrosible zinc and designed to release the radio-pack after an estimated one-year period.

An additional activity undertaken prepreparatory to testing the operation and efficacy of the radio-pack and procedures developed for killer whales, concerned the location and development of an area where

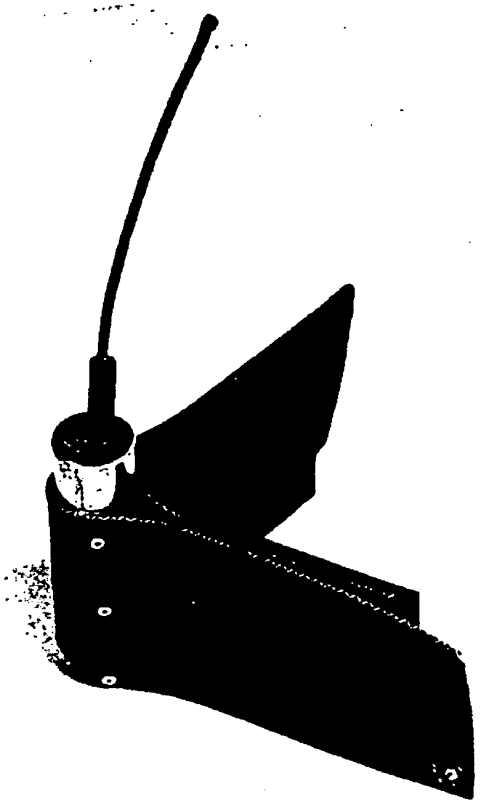

Figure 2. Design of the radio pack installed on the female killer whale.

Figure 3. View of the San Juan Island Kanaka Bay holding pen at low tide.

killer whales to be instrumented could be held for a period of time. The site selected and developed was a small unnamed bay located adjacent to Kanaka Bay on San Juan Island. The lands surrounding this Bay were under lease in part to Sea World, Inc. and in part owned by Dr. Arthur Martin, Professor of Zoology at the University of Washington. Both principles kindly consented to the use of the embayed waters for use in the killer whale studies. Facility support provided at the site by Sea World included a retaining net set across the bay entrance and a trailer laboratory-housing unit. Figure 3 presents a view of the embayment area.

Results

The killer whales obtained for use in this study included an 18-foot male and a 20-foot female. The animals were two of a pod of six killer whales captured by Sea World, Inc. on 7 March 1976 in Budd Inlet at the southern terminus of Puget Sound (Figure 4). The animals were first moved by ship to the Seattle Marine Aquarium on March 14 and 15 and to the San Juan embayment pen on April 5 and 6.

Instrumentation of the Whales

The instrumentation of the female whale was performed at the Seattle Marine Aquarium on April 4, 1976 prior to the transfer of the whales to the San Juan holding site. This procedure permitted the first instrumentation to be performed under quite ideal circumstances. Figure 5 presents a schematic of the manner in which the radio-pack was attached to the dorsal fin of the female whale. Five pins were used to secure the pack and were placed using a hand drill. Four of the pins were set diagonally through the radio harness and the leading edge of the fin so as to lie principally within or just below the heavy skin layer of the dorsal fin. A fifth pin was set crosswise through the fin approximately 2 inches in from its leading edge. Stainless steel washers were then placed on the pins and the timed corrosible release nuts were applied. The nuts were tightened so as to position the pack snuggly but not tightly against the fin. The pins ends were clipped off approximately one-half inch from the surface of the nuts. Figure 6 illustrates the radio-pack as attached to the female whale.

The attachment process was accomplished without noticeable reaction by the whale. There was no bleeding from the pin sites and the animal did not flinch or thrash about at anytime during the attachment process. To limit the possibility of infection the dorsal fin of the whale had been washed thoroughly before the attachment operation and an antiseptic salve was applied over the skin before the radio pack was affixed. Similarly, the self-threading pins had been autoclaved and aseptically wrapped prior to the instrumentation effort and each pin was coated with antiseptic salve prior to placement. The attachment procedure was done under local anesthesia, using 2 percent xylocaine.

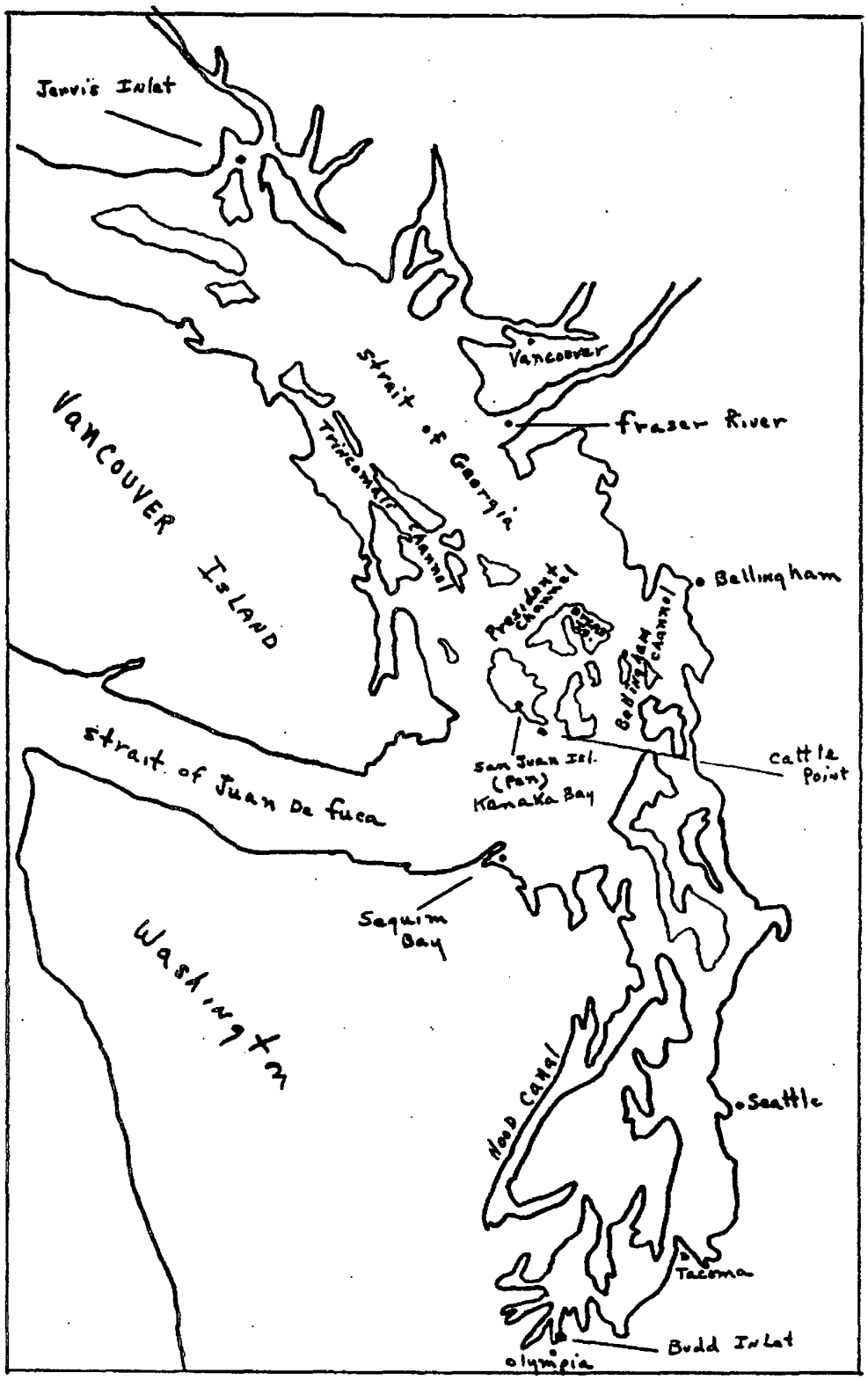

Figure 4. Map of Puget Sound, Juan de Fuca Strait and the Strait of Georgia.

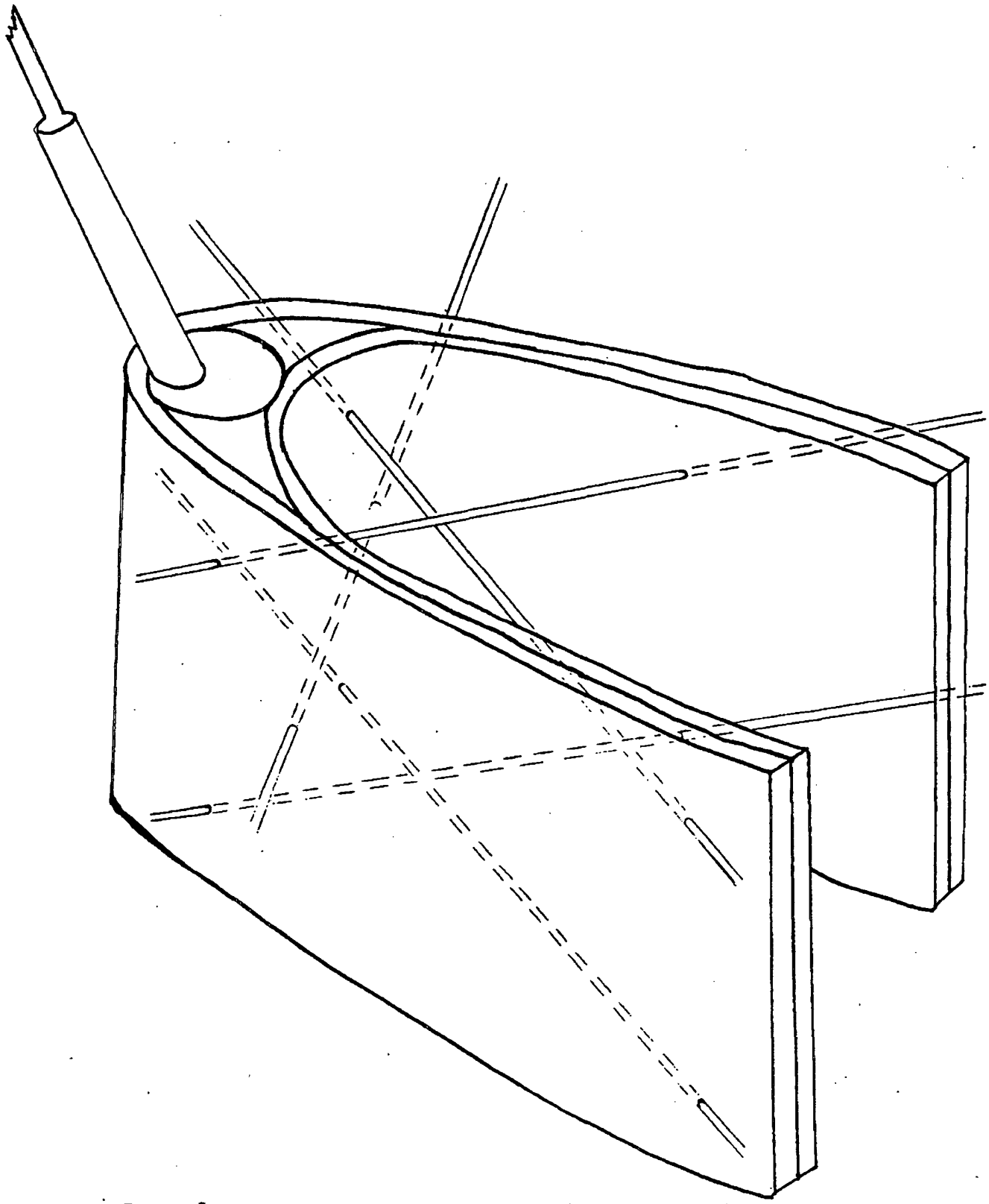

Figure 5. Schematic illustrating procedure by which radio pack was pin-attached to the female killer whale.

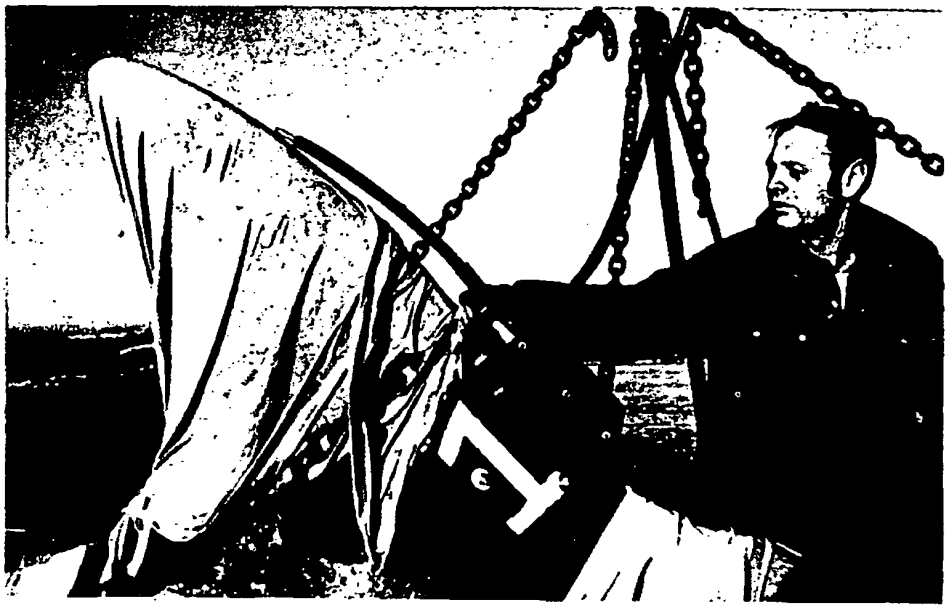

Figure 6. Radio transmitter affixed to female killer whale.

Test Monitoring of the Instrumented Whale

Upon the release of the two killer whales in the San Juan experimental enclosure an around the clock monitoring effort was initiated which concerned (1) the welfare security of the animals (2) behaviorial observations and (3) pre-tests of the radio transmitters and receiving equipment. The security check included a once daily scuba examination of the securing nets and at the minimum bi-hourly examinations of the holding facility and the whales.

Behavioral observations made at the site included respiratory timings, hydrophone recordings of vocalizations, notations of activities including interactions between the two whales, and responses to such stimuli as changes in the tides or to our activities.

Above all, the instrumented whale was observed closely to ascertain whether the radio-pack appeared to disturb the animal behaviorally or to annoy or cause it discomforture. The instrumented animal did not manifest activities of any type which were suggestive of behavioral aberrations as gauged by the comparative activities of the two whales as observed together previously in the Budd Inlet holding pen and at the Seattle Marine Aquarium before the female was instrumented, and as subsequently observed together at the San Juan holding site when only the female was instrumented.

During both the pre and post-instrumentation periods the female whale was the dominant animal. This was manifested as mild aggression which was periodically directed against the male.

The instrumented whale also did not attempt to rub the transmitter against floating objects or manifest other actions which would suggest that the radio-pack annoyed or otherwise bothered her.

Timings of the respiratory cycles of the two whales while retained in the San Juan embayment pen included both visual timings of both whales during the daylight hours and radio timings of the instrumented female on a 24-hour basis. Comparisons of the visual and radio timings of the female were essentially alike as were the comparative visual timings of the male and female whale.

On April 22, 18 days following instrumentation of the female whale, both whales were caught up and examined.

The procedure used in catching up the whales was first to divide the embayment pen in half by stringing a net from the midpoint of the outer enclosure net into shore (Figure 7).

The whales were then forced inshore until stranded in shallow water by a take up net deployed across the seaward side of the pen and slowly worked toward the shore (Figure 7). As the animals stranded they were each tended by two or more persons in diving suits. This attendance concerned (1) preventing the whales from losing bouyancy and (2) keeping them water-bathed once secured. The catching up process was timed to occur just before high tide. Surprisingly, the whales exhibited very little reaction to being caught up except

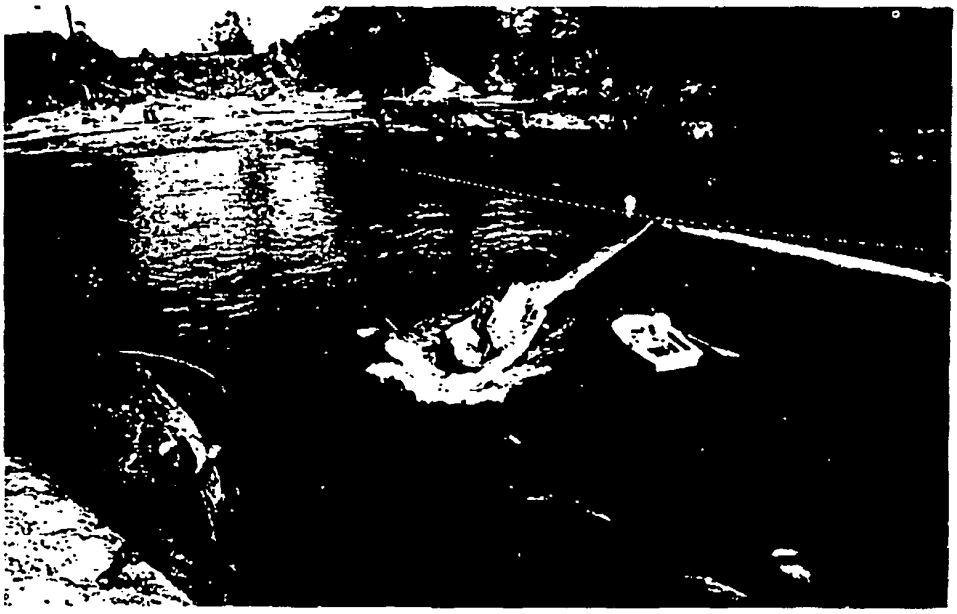

Figure 7. Catching-up the two killer whales in the Kanaka Bay holding pen.

Figure 8. Buoyant state in which the whales were maintained during final instrumentation.

for a great deal of vocalizing and a few seconds of minor thrashing when first stranded. At no time even when initially stranded did the animals make a concerted effort to break back into deeper water which they could easily have done, nor did the whales have to be forcibly stranded or held ashore with the take up net at anytime. Consequently, the entire catch-up process was accomplished without visible trauma to the whales. The state of the tide during the handling process did not pose any problems inasmuch as the whales were maintained in a buoyant state once captured (Figure 8).

Immediately following the stranding of the whales, the instrumented female was examined. This visual examination revealed that the radio-pack was still securely in place and there was no evidence of tissue edema. During the examination the securing nuts were removed from one side of the radio-pack and the skin surface below and the pin sites were examined closely. This examination revealed no evidence of irritation of the skin underlying the radio-pack and there was no evidence of a purulent discharge from the sites suggestive of infection. This analysis was substantiated further from blood samples taken from both animals and later analyzed. These analyses showed no significant change in the blood characteristics of either whale, particularly in the white blood count of the instrumented female, from values determined prior to instrumentation.

A second aspect of the examination concerned the amount of corrosion the self-release securing nuts had sustained during the 18 day attachment period. This was visually discernible and post-weighing of four of the nuts which had been removed yielded calculated retention periods of 119, 128, 134 and 293 days, respectively (Table 1).

Following the examination of the instrumented female whale, the male animal was instrumented. The radio transmitter attached to this whale was identical to the one attached to the female except that the antenna was set to emerge at a 45° angle from the forward edge of the radio-pack rather then emerging directly from the top of the encasement tube (Figure 9). This modification resulted in the antenna setting upright in front of the dorsal fin on the male as contrasted to a position parallel with the leading edge of the fin for the female. The result was that a higher antenna silhouette was achieved and the antenna did not brush the dorsal fin. However, the brushing contact of the antenna against the fin of the female (Figure 6) showed no evidence of abrasion on that animal's fin.

The attachment procedure employed in putting the radio-pack on the male was the same as used for the female's pack with the exception that the fifth pin set across the leading edge of the fin was eliminated (Figure 10). Heavier securing nuts were also used to increase the estimated retention time of the pack on the whale.

At the completion of the instrumentation of the male whale the female whale was to be reinstrumented. The original intention had been to replace the first transmitter with a new transmitter. However, some difficulty was anticipated in securing a new transmitter over the

Table 1. Data and summary results of zinc anode release mechanism developed for killer whale radio packs.

Initial weight of zinc nuts (gms)	Location on radio package	Weight after 18 days (gms)	% weight loss	Calculated estimated days of life[a]	Current measurement estimation days of life[b]
7.45	RRU				
8.95	RRL				
8.16	RFU				
7.95	RFL	6.75	15%	119	
8.52	LRU				
9.41	LRL	8.09	14%	128	
8.1	LFU				
8.09	LFL				
8.22	RC	7.12	13%	134	
8.20	LC	7.69	6%	293	
Avg. 8.30		7.41	9%	-	210-325

[a] Calculated from weight loss while attached to a free-swimming whale for 18 days.

[b] Based on laboratory current measurements and Faradays low. $W=IKt$; $I=0.8 \times 10^{-3}$ milliamps, $K=3.39 \times 10^{-4}$ gm per coulomb, t=time in seconds.

Figure 9. Position of radio-pack and antenna on the male killer whale.

Figure 10. Closeup of radio-pack as attached to male killer whale.

original surgical pins and setting new pins seemed undesirable. Consequently, it was decided to retain the first radio instrumentation rather than prejudice an already proven attachment result. The only loss accompanying this decision was the slightly-reduced transmission life of the original radio. In the reattachment of the pack on the female either new nuts of longer life were used to replace the original nuts or a second nut was placed over the original nuts. In either case the reattachment life of the transmitter was estimated as being one year.

Following the instrumentation process the two whales were released back into the embayment pen for a four day observation period before they were released. This observation period revealed no changes of behavior on a comparison with behavioral traits observed before the final instrumentations and the functional operation of both radios was confirmed.

Release of the Whales and the Tracking Procedure

At the time of the release, two tracking vehicles were in place. These included first the "Propeller" a 65' vessel contracted from and operated by the Sea Scouts, and a Cessna 180 float-equipped aircraft. The prime tracking vehicle was the Propeller which was diesel powered and able to make 9 knots. She was equipped with radar and sonar and capable of continuous all seas operation for two to three week periods. These features were considered necessary to achieve a successful tracking test since it was not unlikely that the instrumented whales would leave the inner waters of Puget Sound.

The technique developed for tracking the whales was to set three Yagi antenna arrays on the masts of the ship. Two of the antenna arrays were set at a 60^{o} angle to either side of the bow of the ship and the third array pointed directly to the rear. In sum, the three antenna arrays monitored the entire 360^{o} area surrounding the ship to a distance of approximately five miles. The area of overlap between adjacent antenna arrays was approximately 30^{o}. The procedure to be used in tracking the whales was to monitor all quadrants during times of general searching and when a signal was picked up its direction was determined by isolating the signal on an individual antenna or by balancing the signals received between two antennas. The more usual procedure was the latter approach since the whales then could be directly trailed using the ship's two forward antennas or tracked abreast by balancing the signal between one of the forward antennas and the rear antenna.

The aircraft tracking vehicle present at the time of release was simply backup insurance in the event of an initial loss of the whales or a failure of the ship tracking technique. The procedure used in locating the whales with aircraft was to affix a Yagi antenna array on either wing strut. As with the antennas used on the ship, the aircraft antennas were capable of isolation by a switch.

Prior to the release of the whales a test of the ships tracking procedure was performed by running the ship out from the pen and performing test monitoring of the whales from various positions relative to the ship's head. This test showed monitoring capability to the anticipated five miles. Previous tests had already established the workability of the aerial monitoring procedure except that the brief surfacing times made location of the signal direction difficult.

The two radio instrumented whales were released at 1300 on 26 April. The release was accomplished by simply folding back one-half of the net securing the bay. During the pulling back of the net two small boats were stationed in the take up area to keep the whales away from the net. This precaution proved unnecessary, however, and several minutes passed before the whales could be induced to leave the pen once the net was folded back. This they did slowly and deliberately and soon after the animals were observed moving to the outer sea.

Tracking Results

Following the release of the whales, the animals were tracked continuously over the next ten days except during two periods when position contact was lost for 9 and 12 hours, respectively. The continuous tracking effort was terminated on May 5 due to severe radio interference in the Bellingham, Washington area.

Subsequent efforts made to monitor the whales included periodic shore, air and ship radio searches, visual air and ship searches and reports from observers. These efforts resulted in eleven contacts or reports of the whales over the subsequent five months (Table 2).

During the initial ten day tracking period the whales were tracked 191 hours and 21 minutes during which period they traveled a measured minimum 531.8 nautical miles (Table 3). The actual distance traveled by the whales during this tracking period was undoubtedly somewhat greater than the recorded distance since our calculations were based on straight line plots between observations or radio locations of the whales.

During the tracking period the mean hourly travel speed was 2.8 nautical or 3.2 statute miles (Table 3). There were relatively few instances of rapid travel by the whales and all of these were for relatively short periods. The three maximum measured speeds were 16.8, 15.8 and 15.6 nautical miles per hour for periods of 10, 8 and 5 minutes, respectively. The longest measured run at speed was 11.4 nautical miles per hour for a period of 20 minutes.

The average daily travel distance of the whales based on the six full days the whales were tracked was 68.13 nautical or 78.3 statute miles (Table 3). Comparable values were realized using the mean travel speed calculated over the entire tracking period. The greatest and shortest distances traveled during a single day were 74.2 and 57.9 nautical miles, respectively.

Table 2. Visual and Radio Contacts of Two Radio-marked Killer Whales.

Date Period	Location	Type of contact
4/26-5/5	San Juan Islands and Lower Georgia Strait	Visual and radio tracking by ship.
5/8	Mid-San Juan Islands	Air radio contact.
5/9	San Tricomali Channel area, B.C.	Air radio contact.
5/11	Points along northern edge of Orcas Island	Shore radio contact.
5/12	Sequim Bay	Observer report.
5/12-5/13	Sequim Bay and immediate off shore waters	Tracking by ship.
5/16	Jervis Inlet, B.C.	Observer report.
7/29	President Channel opposite Waldron Island	Observer report.
8/13	Cattle Point at southern tip of San Juan Island	Tracking ship radio contact.
9/10	Mouth of Fraser River, B.C.	Observer report.
9/15	Lilm Kiln Point, southern edge San Juan Island	Observer report.
9/16	Sucia Island area	Shore radio contact.

Table 3. Killer Whale Tracking Data.

Date	Hours tracked	Nautical miles traveled	Hourly rate of travel (in knots)
4/26/76	10.07	23.20	2.30 Knots/hr.
4/27/76	24.00	57.90	2.41
4/28/76	14.28*	23.60	1.65
4/29/76	23.98	68.10	2.84
4/30/76	24.	61.40	2.56
5/1/76	23.95	72.70	3.04
5/2/76	12.07	37.60	3.12
5/2/76	11.53**	29.0	2.47
5/3/76	24.08	74.2	3.08
5/4/76	23.90	73.90	3.09
5/5/76	11.00	39.2	3.56
TOTAL	191.33	531.8	2.78

* In radio contact for remainder of day but unable to accurately plot the remaining hours.

** Time and distance between points where whales temporarily lost and again picked up (time and distance not included in totals).

As is to be noted by reference to Figure 11, the travel distances of the whales was highly variable between hourly periods. However, the data do suggest six relatively regular alternating periods of high and low travel. The reason for this pattern is not clear. Two possibilities are alternating periods of active travel and slow resting type travel, or periods of relatively sustained travel interrupted by periods of feeding activity.

Figure 12 depicts the travel course of the two instrumented whales over the initial 10-day tracking period and the locations where the whales were subsequently observed or monitored. During the ten-day tracking period the whales traveled extensively throughout the San Juan and Gulf Islands, lower Georgia Strait and the eastern end of the Strait of Juan de Fuca. Subsequent locations where the whales were observed or radio located included several sites in these same waters and observations at the mouth of the Fraser River and in Jervis Inlet, British Columbia, Canada. The latter sighting was in excess of 125 miles north of the most southern sighting of the whales in Sequim Bay, Washington.

Diving Data

During the period that the radio-marked whales were being tracked an effort was made to determine the blow cycle* of the animals according to their activity and by time of day. The radio signals afforded a unique opportunity for the precise determination of these data. The blow phase of the cycle was measured by the presence of a radio signal and the dive phase was measured by the intervening absence of a radio signal.

The normal dive cycle of the whales consisted of a dive of several minutes duration followed by three or four brief surfacing blows and short shallow intermittent dives. An extensive series of timings revealed each of the brief surfacing blows to be 3 to 4 seconds in duration. The short dives between blows were quite variable in length but averaged 21 seconds. Thus, in the normal blow cycle the 3 or 4 surfacing blows of the whales were confined to approximately one minute of the total blow dive cycle. The only significant variation from this pattern was when the whales were actively feeding or on a few occasions when they briefly rested or slowly swam at the surface of the water.

Table 4 presents a summary of the blow cycle of the radio-marked killer whales for the seven days that these data were compiled. The mean length of the blow cycle over these seven days based on 1365 timings was 5.77 minutes. The shortest daily mean blow cycle was 4.64 minutes and the longest 6.50 minutes.

Figure 13 presents the blow cycle of the whales over the seven day recording period as hourly averages. These data show shorter

* Period of surfacing during which respiration or "blowing" occurred.

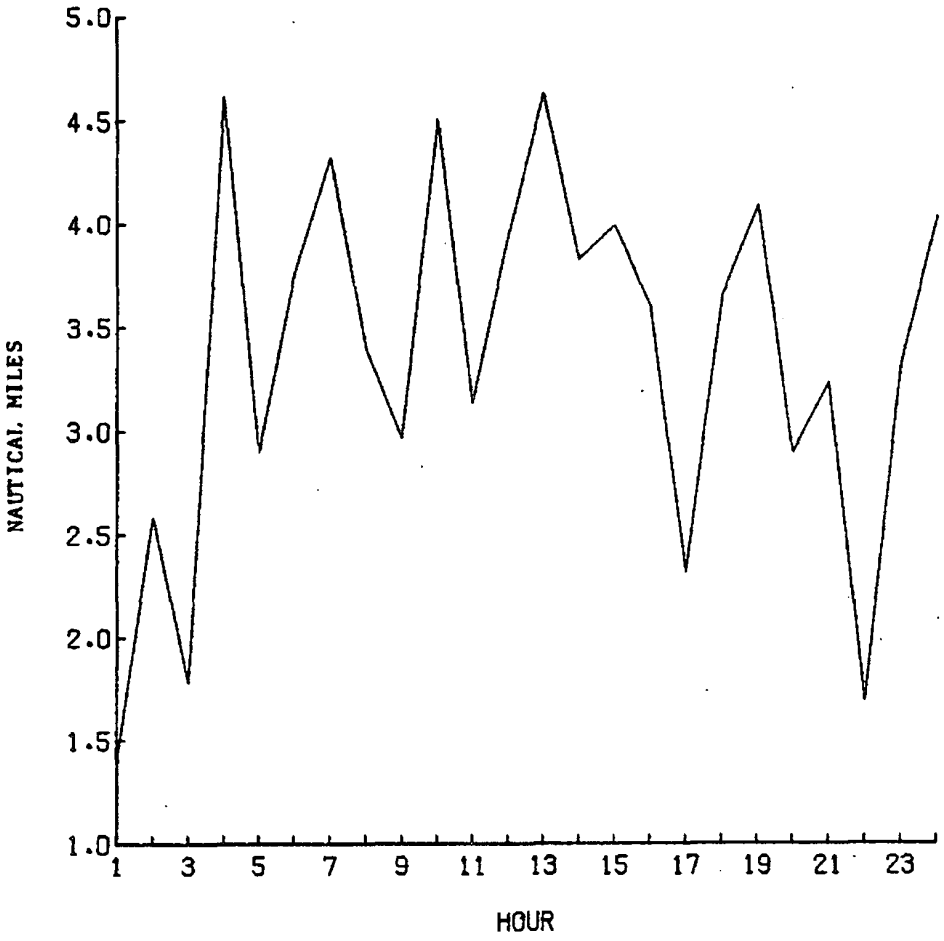

Figure 11. Mean hourly travel distance of the radio-marked killer whales.

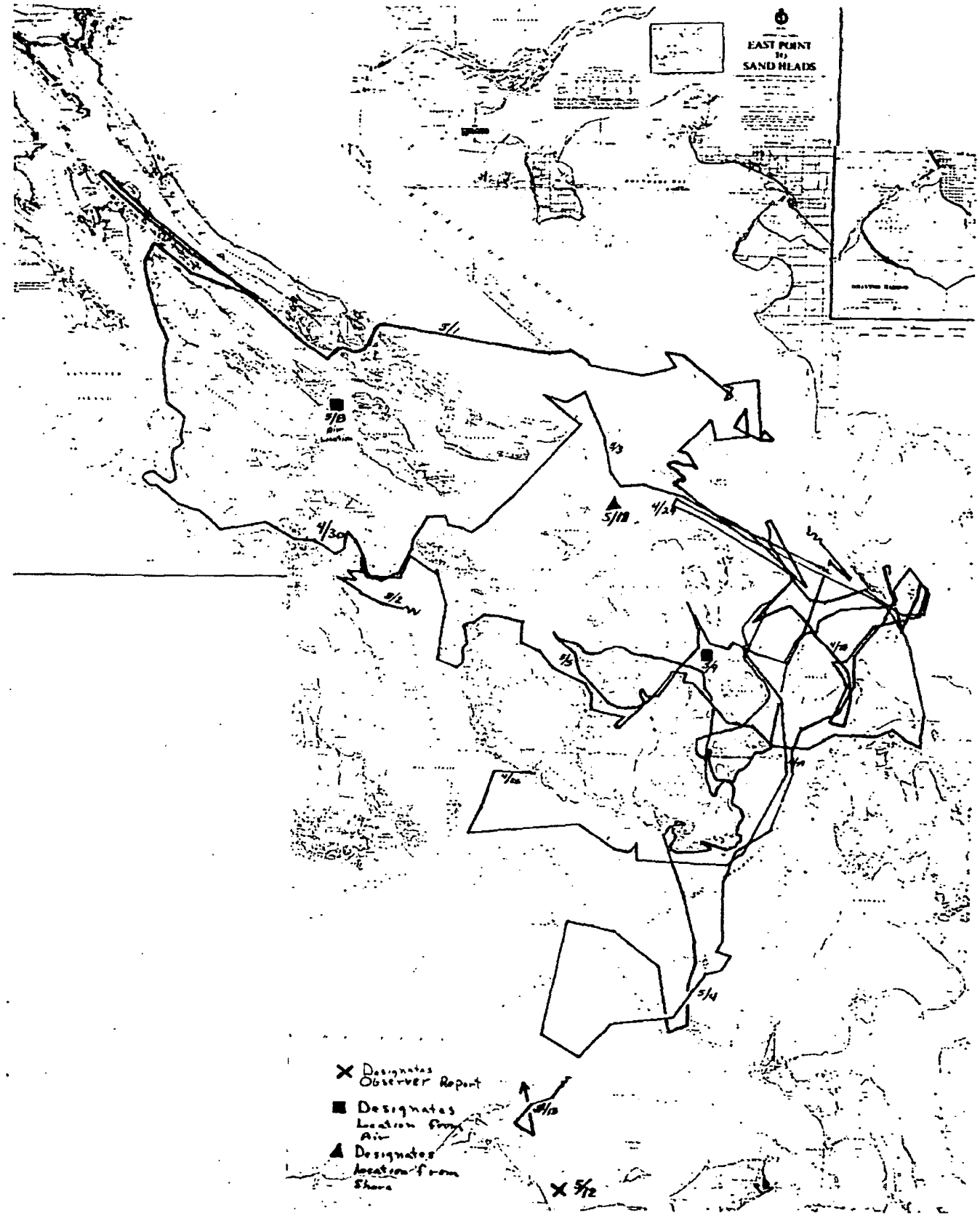

Figure 12. Course of travel of the two radio-marked killer whales during the ten days immediately following release.

Table 4. Summary of blow cycle data by day.

Date	No. of blow cycle timings	Total minutes of blow cycles timed	Mean blow cycle length (in minutes)	Variance (S^2) in cycle length
4/26/76	No	Data		
4/27/76	"	"		
4/28/76	"	"		
4/29/76	214	993	4.64	1.69
4/30/76	232	1317	5.68	1.63
5/1/76	200	1301	6.50	1.24
5/2/76	124	712	5.74	3.09
5/3/76	236	1378	5.84	1.88
5/4/76	232	1408	6.07	1.44
5/5/76	127	768	6.05	.69
TOTAL	1365	7877	5.77	.19

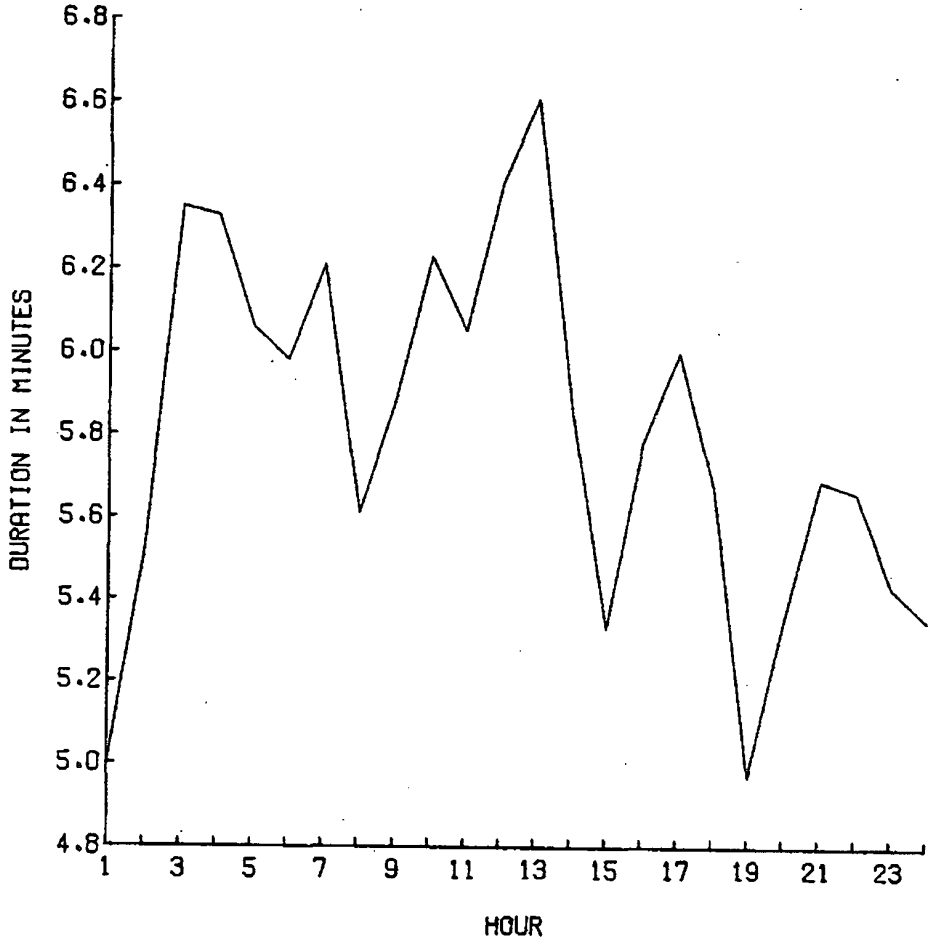

Figure 13. Mean hourly blow-cycle of the radio-marked killer whales.

dive durations during the late afternoon and evening than during other times of the day. This period is believed to correspond with the whales major feeding activity.

Figure 14 shows the distribution of dive times during periods of active travel, milling/feeding, and active feeding. Active feeding was feeding concentrated in a local area. Conversely, milling/feeding was feeding activity which was spread over a several mile area. As may be noted in Figure 14, there was very little difference in the diving durations of the whales while traveling and milling/feeding. This is in marked contrast to the shorter diving durations recorded for the whales when actively feeding (Figure 13).

The longest dive time recorded for the whales was 17 minutes and less than 20 of the 1365 dives timed exceeded 11 minutes (Figure 13).

Photo Identification Studies

During the months of June, July and August three five-day searches were made of the San Juan Island area to attempt to locate and photo-identify killer whales. The animals sought in this effort were: (1) the marked killer whales to ascertain whether the radio-packs had, in fact, detached, and (2) a characterization of the whales in "J" pod, the killer whale pod identified as the most discrete resident pod of whales occurring in the waters in and adjacent to Puget Sound (Bigg, MacAskie and Ellis (1976) and Balcomb and Goebel (1976)).

These field searches resulted in encounters with "J" pod on June 22 and again on June 23. On June 22 the whales were intercepted at Sunset Point at the southwest corner of San Juan Island at 11:30 a.m. They were subsequently trailed and photographed until 7:30 in the evening at which time they were in Speiden Channel at the north end of San Juan Island. On June 23 the whales were intercepted at 12:30 a.m. in President Channel just south of Waldron Island. The whales were subsequently followed until 7:30 p.m. during which time they proceeded north through boundary passage and across Georgia Strait to the Pt. Roberts area.

During both encounters extensive color and black and white photography was taken of the whales. Subsequent analysis of the photographs revealed the composition of the two whale assemblages as apparently the same. In any event, the whales which were readily identifiable on the basis scars or saddle patch markings were present in the pod during both of the observation periods.

The number of whales observed during the encounters was either 16 or 17. Of these, the adult whales were the same animals as reported as present in the pod during 1976 by Balcomb and Goebel (1976). These included three large males, J-1, J-3, and J-6 and a

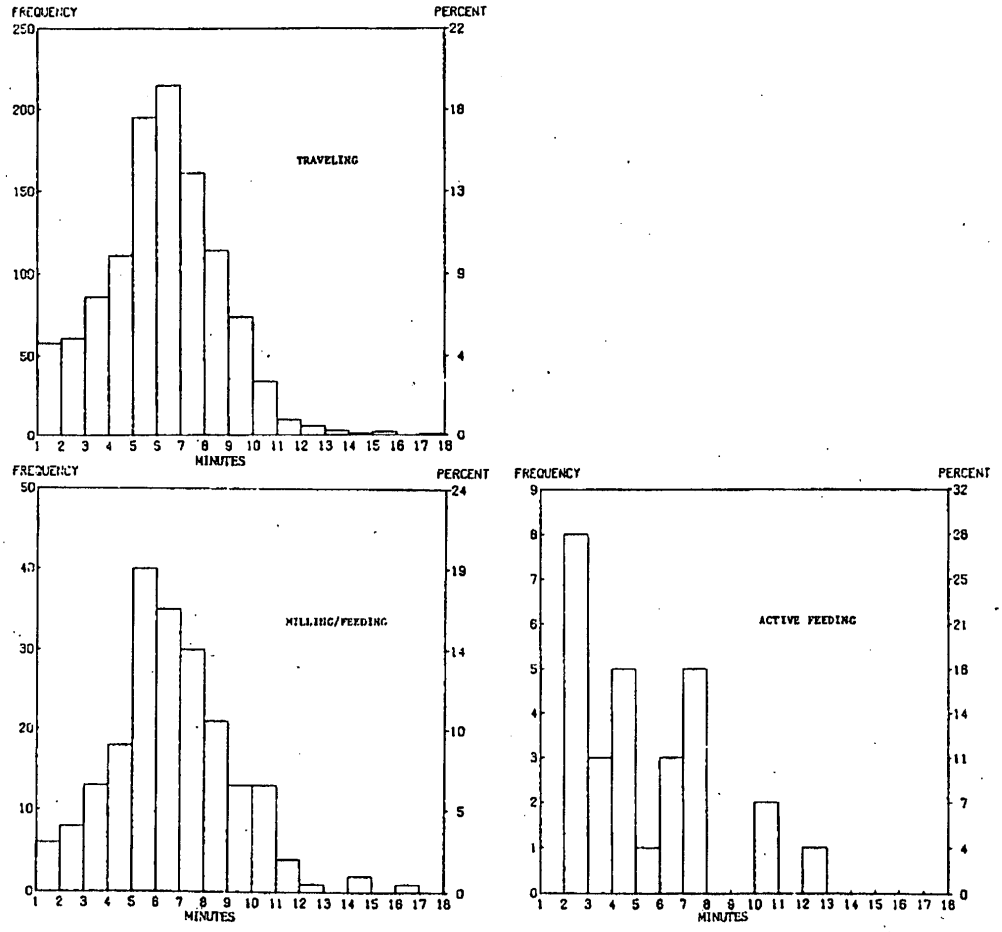

Figure 14. Distribution of blow-cycle durations by type of activity during travel periods.

presumed eight females, J-2, J-4, J-5, J-7, J-8, J-9, J-10 and J-12. Calves present in the pod numbered five and possibly six. Females quite definitely accompanied by calves included J-2, J-4 and J-5. The remaining calves showed no definitive association with any of the pod females although J-10 was frequently accompanied by a calf. The calf of female J-5 was young and a new birth since the conclusion of the National Marine Fisheries Service study in October of 1976. Calf J-15, a new birth in 1976 (Balcomb and Goebel 1976) still closely accompanied its mother, J-4.

In the limited photography effort in this study, it became apparent that both the identification of calves and determinations of their mothers was difficult. First they were difficult to identify by photography. This was in part due to apparent shielding of the calves by other whales. The calves also had indistinct saddle patches and few if any discernible scars. Further, many of the scars identified in the Balcomb and Goebel study were largely indiscernible in the current photography. These factors, plus the rapid growth of the calves and an apparent loose calf-cow bond in older calves renders photo-documentation of their status questionable unless performed at three or four month intervals.

Discussion

The results of the development research conducted under this contract would appear to have significantly contributed to the art of radio tracking technology as directed toward studying cetaceans.

While the radio-marked whales were not monitored over the one-year design life of the radio transmitters and the self detaching mechanism, the evidence gathered showed that the radios were still in place and operating five months following first attachment. Accordingly, two key objectives would appear to have been achieved. These include the successful long-term attachment of radio-packs to killer whales and the development of a radio transmitter capable of long term operation under field conditions. The success of the attachment technique is considered the singular most significant result in view of the difficulties a number of investigators have experienced in achieving long-term radio attachments on cetaceans (Kaufman and Irvine (1975)). The procedure employed here is believed to have succeeded because (1) the pack was firmly secured so that it could not swivel or work, and (2) the attaching pins were set so as to lie principally within or just under the skin rather than being set in the tissue of the fin core. As a result tissue rejection and/or pressure tearing apparently was obviated.

As regards the radios, the initial main concern with their performance was the antenna. It would have been preferable to pot the whip antennas in the harness collar proper such that the antennas would not have been subject to flex breakage. This was not done as it was felt that a fairly high antenna silhouette would be required

to give sufficient signal output for tracking, particularly when there was any wave action. The whip design developed withstood breakage over the known five month attachment period.

Although a fair measure of success was achieved in tracking the whales using the multi-array receiver antenna design, the procedure was exceedingly demanding of manpower effort and time.

As regards the tracking effort, this required the undivided attention of one person on headphones at all times. As a rule the whales made three or four consecutive surfacing blows over a 30-40 second period every six to eight minutes of time. During these surfacings which averaged 3-1/2 seconds or 6 to 8 radio pulses, the headphone operator had to switch between the various antennas to determine which antenna carried the strongest signal. If the signals were not balanced, the headphone operator would then have the ship swung and on the next surfacing he would again attempt to achieve a balanced signal and thus determine the directional position of the whales. Distances of the whales from the tracking ship were known only generally except when the animals were observed visually. However, the distance between the ship and the whales was maintained relatively constant at about one-half mile as was ascertained by radio signal strength and the temporary loss of the signals as the animals passed around islands or peninsulas ahead of the ship. As a rule, following the whales was usually not particularly difficult except when they fed and, of course, when signal interferences occurred. On a number of occasions radio interference was severe and on three occasions it caused losses of contact with the whales. Procedures for countering this might include changes of radio frequency and greater filtering out of the signal received. Helpful, too, would be a direction finder receiver. Such a finder was purchased from Ocean Applied Research Laboratories and its use should greatly aid future tracking efforts. However, tests of this unit have yielded distances less than one-half of the distances possible with the Yagi antenna array. Consequently, a coupling of the systems together would appear desirable.

The greater need for a direction finder device at this time concerns attempts to monitor whales from the air. In the current generation of studies, signals were regularily received from aircraft but the very short transmission periods, the long down times and the fact that the aircraft was traveling at relatively high speeds all keyed together to render air position monitoring as nearly unworkable with the receivers used.

As concerns the biological data resulting from the test of the tracking technology, the great amount of daily travel was unanticipated.

As concerns the results of the limited photo-identification study performed under this contract, it is apparent that the technique has definite value in population studies of killer whales.

This appears particularly so as regards the life history of individual resident pods, i.e., longevity of individual whales and reproductive recruitment. On the other hand, the efficacy of the procedure for assessing the population status of whales in an area appears somewhat problematic. The studies of Balcomb and Goebel (1976) and of Bigg et al. (1976) while providing a base orientation of killer whales in the waters of Washington State have not been of sufficient detail or duration to provide a clear understanding of the distribution, status and population characteristics of the killer whale stocks inhabiting these waters. With the exception of J-pod which appears to be resident and stable, the remaining pods of whales identified in Puget Sound, lower Georgia Strait and the Strait of Juan de Fuca appear to be either transient whales or numerically unstable resident pods. Although two of these pods (K and L pods) have been classified as resident pods by Bigg et al. (1976) and Balcomb and Goebel (1976) these researchers are in disagreement as to whether L-pod is, in fact, one or two pods. Further, these researchers reported the regular joining together of the assumed resident pods and the occasional presence of individuals from one pod with other pods. Taken together these observations render suspect the fidelity of specific whales to particular pods and thus of the integrity of the pods.

The reports of the photographic studies appear further to assume that all of the whales present in the inland waters were identified. This assumption appears unwarranted in view of the fact that the whales captured in the radio-marking study had not previously been identified and further the radio-marked whales were not observed by the photographic teams during the five month period that the animals were at least periodically present in the study waters. Further, Bigg et al. recorded seven transient pods in lower Georgia Strait none of which were observed during the National Marine Fisheries Service study. These observations indicate that the observational incidence of killer whales in Washington waters is low and/or that major differences exist in the numbers of whales which occur in Washington waters between years.

A second required point of clarification is the seasonal distribution of killer whales in Washington waters. Balcomb and Goebel (1976) regularly observed whales during the period June through October but observed only 3 pods in April and none in May. Their survey did not cover the months November through March and the study did not include most of the waters of Juan de Fuca Strait and it addressed only lightly the waters of lower Puget Sound. Consequently, the relative seasonal distribution and abundance of killer whales in the waters of Washington State is unknown.

A third major unknown as regards the killer whales associated with the waters of Washington State is information on population turn-over and reproductive recruitment. The photographic surveys

identified the composition of the resident pods of killer whales observed as being approximately 20 percent adult bulls, 20 percent calves and 60 percent undifferentiated animals. The latter were presumed to include primarily females and immature males. While the 20 percent calf figure is suggestive of recruitment, the reproductive recruitment rate of the assumed resident pods is uncertain since the calf group is suspected of containing several year classes of whales. As regards turnover rate or age or sex specific mortality, sufficient studies have not been performed to provide a measure of this. A major point in ascertaining this by use of the photo-identification procedure concerns the persistence of the identification markers. While identification scars and saddle patch markings appear to be relatively long lived on older animals, the persistence over time of the identification markers on younger whales is unknown.

These considerations suggest that a detailed evaluation of the photo-documentation procedure is in order to determine the degree to which the technique can be relied upon to assess the status of killer whales in Puget Sound and adjacent waters.

Recommendations

The results obtained in this study demonstrate the value of controlled procedures in the development of new technologies as opposed to direct field applications of yet unproved procedures.

A number of recommendations for future studies relative to the investigations performed under this contract can be made. One area requiring particular investigation concerns long term (one year minimum) attachment procedures. Ideally these studies should be performed in semi-natural environments such as the embayment enclosure utilized during the current studies. The health and behavioral responses of radio-marked animals to the instrumentation procedures should be an intergral aspect of this research.

A further line of recommended research is the development of projectile radio transmitters. While it is expected that such radios will have limited attachment life, the radios would appear to offer enlarged opportunities to study the larger cetaceans inasmuch as captures of even killer whale sized cetaceans is extremely difficult and expensive. Short term radio-taggings of this type may also permit tracking for sufficient periods as to identify areas and times when whales might be vulnerable to conventional net captures.

A further line of research desired as concerns radio attachment procedures includes refinement of the technology for releasing the radio-pack once the life of the radio has been expended. Ideally, tests of this technology should be performed using captive animals.

Necessary research of the radio transmitters principally concerns lengthened life of the transmitters and miniturization of

the radio-package. A logical candidate procedure for lengthening the life of the transmitters would be the addition of a water switch which would turn the radio off whenever an instrumented whale dived. Ocean Applied Research Labortories incorporates a pressure operated switch on radios developed by that firm. Additional research of the transmitting antenna is also desired as regards breakage and possible corrosion effects.

As concerns the radio receivers, particular research is required to develop filters to screen out all but the exact transmitting frequencies. Additional work may also be required as concerns a directional receiver although the directional receiver of the Ocean Applied Research Corp appears quite good except for its limited range.

A further technological approach desired for an area such as Puget Sound would be the development of a net of automatic receiver stations which could monitor the movements of transmitted whales as they passed given points. In the case of the Puget Sound area a 3-array station could possibly serve to monitor the movements of transmitted whales as they passed through the general San Juan area. Doubtless, the development of such stations would require considerable electronics research but the rewards of the effort should justify the expense.

Lastly, consideration should be given to developing a transmitter for killer whales suitable for tracking by satellite telemetry. The National Marine Fisheries Service is currently investigating the potential of tracking porpoises by satellites relative to the tuna-porpoise problem. However, current indications are that it will be some time before transmitters are sufficiently miniturized for use on porpoises. Further, the question of suitable attachment procedures for porpoises remains unsolved. These problems are far less restrictive as regards the killer whale. Consequently, it would appear to be a species of choice in the development of satellite telemetry for cetaceans.

As concerns studies of the killer whale employing the photo-documentation procedure, a major full year study is recommended to assess the suitability of the technique for assessing the year long distribution and status of killer whales in Washington waters. As opposed to earlier studies it is recommended that this effort be distributed relatively uniformily in the state's waters as opposed to the area limited study performed by the National Marine Fisheries Service in 1976.

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Appendix 1

UNIVERSITY OF MINNESOTA
TWIN CITIES

Department of Ecology and Behavioral Biology
108 Zoology Building
Minneapolis, Minnesota 55455
(612) 373-5177

October 14, 1976

Dr. A. W. Erickson
Professor of Wildlife
College of Fisheries
University of Washington
Seattle, Washington 98195

Dear Al:

Here are the specifications on the transmitters --

Frequency: 164 MHz, nominal. Actual frequencies used:

1) 164.150 MHz
2) 164.225 MHz
3) 164.350 MHz
4) 164.650 MHz
5) 164.500 MHz
6) 164.400 MHz
7) 164.400 MHz

Battery:	Power Conversion, Inc. Model 660-4, 2.8 volts output, 416 milliampere days capacity, two cells in series, 5.6 volt power.
Pulse repetition rate:	Approximately 100 pulses/minute
Pulse duration:	20 millisecond minimum 35 millisecond average
Current drain:	0.4 milliampere (average)
Encapsulation compound:	3M Scotchcast #5 electrical resin
Antenna:	Stainless steel 8/32 (7 x 7) vinyl coated. 17" long. Reinforced rubber tubing used to make stand upright.
Power output:	Approximately 10 milliwatt peak

Harness material:	1) Neoprene - impregnated cotton duck 4 ply, 1/8" thick (white material)
	2) PVK 120 simple ply polyester/polyvinyl (black material)
Cushion material:	Neoprene sponge, soft density open cell, 3/16" thick. Bonded to harness material with Plio-bond adhesive.
Rivets:	Stainless steel
Tubing:	Stainless steel, or schedule 40 PVC pipe
Circuit diagram:	Enclosed

This may not be exactly the form you wanted, but it is the only way to give a fairly complete description. If you only want to use a short description, I suggest something like the following:

> Transmitters used were crystal controlled pulsing continuous wave at 164 MHz. The transmitter pulsed at a rate of about 100 pulses per second and were on for about 35 milliseconds. The power source was two lithium cells in series, with an average drain of 0.5 milliamps. The antenna was a 1/4 wave covered vertical whip.

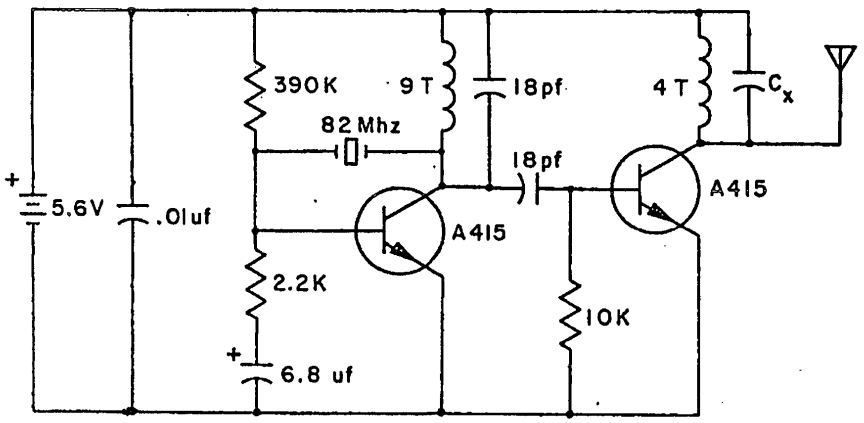
You can describe the harness as you want. Hopefully this fills your needs by way of description.

Sincerely,

Larry Kuechle

LK:gle
Enc.

164Mhz TRANSMITTER



C_x - Selected for max. power output, 3-5pf typical.