30369

WORKSHOP TO ASSESS POSSIBLE SYSTEMS FOR TRACKING LARGE CETACEANS

24-26 February 1987

Northwest and Alaska Fisheries Center
Seattle, Washington

BACKGROUND DOCUMENTS

Background Documents for

Workshop to Assess Possible Systems' for Tracking Large Cetaceans

CONTENTS

INFORMATION FOR PARTICIPANTS

Workshop to Assess Possible Systems for Tracking Large Cetaceans

TIME	24 February 1987	9:00 a.m.-6:00 p.m.
	25 February 1987	9:00 a.m.-10:00 p.m.
	26 February 1987	9:00 a.m.-noon

MEETING PLACE — First floor conference room, Building One (1) of the Northwest and Alaska Fisheries Center, 7600 Sand Point Way, NE, Seattle, Washington

ACCOMMODATIONS — A block of rooms has been reserved at the University Plaza hotel, 400 N.E. 45th Street, Seattle. The room rates are $39.00 for a single room and $45.00 for a double room, plus a 12.9-% tax. The hotel phone number is (206) 634-0100. Participants are responsible for making their own room reservations.

IF YOU COME BY AIR — The University Plaza hotel is on the route of the Ease Everett Airporter Shuttle. The shuttle leaves the Seattle/Tacoma airport every hour on the half hour from 6:30 a.m. to 8:30 p.m. After 8:30 p.m., there are runs at 9:45, 10:45, and 11:45 p.m. The trip from the airport to the hotel takes approximately 1/2 hour and costs $7.00 one way and $12.00 round trip. No reservations are required for the airport pick-up. Reservations should be made a day in advance for the hotel pick-up (206/743-3344). At the airport, the shuttle stop is on the lower level at the far north end, past the United baggage claim area.

Draft Agenda

WORKSHOP TO ASSESS POSSIBLE SYSTEMS FOR TRACKING
LARGE CETACEANS

24 February

9:00-9:15 Welcome and Introductions

9:15-9:30 Review of Workshop objectives

9:30-9:45 General overview of cetacean conservation problems requiring movement or other types of data that might best be obtained by satellite-linked radio tracking or other types of telemetry

9:45-10:15 Discuss and agree, as possible, on performance standards and technical specifications for a successful cetacean tracking system

10:15-10:30 Coffee break

10:30-12:30 Review and critique past and planned efforts to radio tag and track large cetaceans

- J. Goodyear
- S. Swartz
- A. Martin
- W. Watkins
- B. Mate

12:30-1:45 Lunch

1:45-3:15 Review other radio tagging/tracking programs that may contribute to identifying and resolving problems concerning large cetacean tagging/tracking

- K. Frost (beluga whales)
- G. Rathbun (manatees and dugongs)
- R. Hill (Antarctic seals)
- S. Fancy (polar bears, caribou, walrus)

3:15-3:30 Coffee break

3:30-4:30 Review existing satellite tracking system and constraints (D. Beaty and/or S. Tomkoewitz)

4:30-6:00 Review problems that have been encountered and identify steps that possibly could be taken to overcome problems with--

Tag retention (Discussion leader to be named)
Delivery systems (" " " " ")
Transmitters (" " " " ")

Batteries (Discussion leader to be named)
Antennas (" " " " ")
Satellites (" " " 1! II)
Accessing data (" " " 1! ")
Other (" " " " ")

6:00 Adjourn

25 February 1987

0900-1015 Continue identification and discussion of steps that possibly could be taken to ovecome identified problems

10:15-10:30 Coffee break

10:30-11:15 Identify other possible means (e.g., acoustic tracking for obtaining needed movement or other data

11:15-12:00 List and, as possible, rank identified research and development tasks according to the likelihood that they will contribute to development of a safe and effective system for tracking large cetaceans

12:00-12:15 Constitute working groups to develop work .statements and estimate the time, money and special logistic requirements necessary to complete identified tasks

12:15-1:30 Lunch

1:30 Working group meetings

26 February 1987

9:00-11:00 Review and discuss working group reports

11:00-11:45 Review principal workshop findings and conclusions

11:45-12:00 Review plans for preparing and distributing the draft workshop report

12:00 Adjourn

BOWHEAD WHALE RADIO TAGGING FEASIBILITY STUDY
AND REVI EW OF LARGE CETACEAN TAGGING

by

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ABSTRACT

This report reviews marking and tagging techniques, their feasibility, success, and history of employment on large ceta ceans. Static tags, freeze branding, paint marking, natural marks, and sonic tags are discussed. Emphasis is placed on radio tags. Three radio tracking systems and four types of radio transmitter attachments currently available for large cetaceans are evaluated and discussed.

Results of a feasibility study using a VHF radio tracking system on bowhead whales are presented. On 20 and 21 August 1981 radio tags were deployed on two howhead whales (Ba laena mysticetus) in the eastern Beaufort Sea (69°54'N x 132°12'W). From one whale, signals were received intermittently for 10 rein, the other, for one and one-half hours. Reliable dive-surface profiles of tagged whales from these transmissions were not possible. However, dive-surface profiles are reported for a bowhead whale identifiable by natural marks. Efforts to relocate tagged whales from ship and three aerial receiving stations were unsuccessful.

Aerial surveys were flown from 20 July through 12 September, initially to locate whales but ultimately to relocate and track tagged animals. Efforts to relocate tagged whales continued from 16 September through 13 October in collaboration with a BLM (Bureau of Land Management) howhead survey team working in OCS (Outer Continental Shelf) lease-sale areas. A brief radio transmission was received during one of these surveys but the presence of a tagged whale was unconfirmed by either further transmission or visual relocation. A record of all species of marine mammals sighted on surveys is presented.

The development of a satellite-linked transmitter and requirements for a successful satellite tracking program are discussed.

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INTRODUCTION

There are essentially three types of research possible utilizing radio tracking technology: 1) short term behavior, activity, and habitat utilization studies; 2) longer term migration and distribution studies, and 3) telemetry studies yielding information about the physiological state of the whales and about their environment. Standard radio frequency (RF) tracking techniques can be used to gather data on behavior (including effects of human disturbance), activity patterns, and telemetry on a short term and rather local basis. However, to gather longer term information on habitat utilization, distribution, migration, and long term physiological and environmental parameters, satellite-linked technology is essential, since logistical and cost factors preclude any other method of signal acquisition.

The purpose of this research was to provide an overview of radio tracking potential for large cetacean research, to test the feasibility of radio tracking bowhead whales, and to initiate the development of a satellite-linked transmitter (SLT) for the remote acquisition of whale location, movement, and distribution data. The specific Objectives of the program were to:

1) synthesize existing information on tagging and tracking systems, addressing the advantages and disadvantages of individual tags and tracking systems for large cetaceans, and identify the technology gaps necessary to advance the state of the art to a safe and reliable level:

2) conduct a field experiment to determine the feasibility of radio tagging and tracking howhead whales in Lhe Beaufort Sea, ultimately via satellite; and

3) design, fabricate and test an SLT for attachment to large cetaceans.

REVIEW OF LARGE CETACEAN TAGGING AND MARKING TECHNIQUES

History

Although man since the earliest Limes, has studied the lives of the other animals with which he shares his world not until the nineteenth century were systematic marking programs carried out to aid those investigations. Prior to that time careful field studies had provided a large accumulation of information concerning some phases of wildlife natural history, but scientists recognized the need for more information about territory and home range, social structure, population structure, and migration routes. Thus tags and marks that had been used primarily Lo establish ownership or to carry messages were modified, improved, and used in conjunction with newly evolving analytical techniques for the rigorous study of the ecology and behavior of animals.

The earliest marking studies were carried out on birds and fish. Fisher and Peterson (1964) ascribe the first bird marking to Quintus Fabius Pictor. "Sometime between 218 and 201 B.C. , when the second Punic War was on, this Roman officer was sent a swallow tsken from her nestlings, by a besieged garrison. He tied a thread to its leg with knots to indicate the date of his relief attack, and let the bird fly hack." By the eighteenth century a wide variety of birds including falcons, herons, swans, and ducks were marked wiLh various types of name plates and metal collars, and during the late nineteenth century a Dane by the name of Mortensen developed the aluminum leg band which was the foundation for all subsequent bird handing. By the nineteenth century various fish species were also being marked. Early salmonid studies using ribbon, brass wire, fin cutting and numbered tags demonstrated that these species returned to their native rivers to spawn after spending several years at sea.

The first mammals to be systematically marked were the northern fur seals of the Pribilof Islands in the midnineteenth century. The seals were marked by removal of the ears to determine their dispersal, movements, and homing specificity to the rookery of their birth. Later, fur seals and other pinnipeds were marked by a variety of methods including branding, dyeinq, painting, hair removal, and many different tag types (Scheffer 1950; Hobbs and Russell 1979). By the 1930's the marking of small mammals had become a routine method of study, but the capture and application of tags and marks to most large mammals still proved difficult. It was not until the development of safe drug immobilization techniques in the 1960's that other large mammal marking became a significant research technique. A thorough review of the history and use of animal marking and tagging is found in Storehouse (1978) .

Although a large number of marking and tagging techniques have been developed and used for the study of animals, most cannot be used successfully on cetaceans because of their physical characteristics, habitat, and general invisibility shove the water surface. Cetaceans have no hair and their epidermal tissue sloughs very rapidly so it is impossible to clip them or mark them with paints or dyes. Their body shape, fusiform and highly adapted for aquatic living, makes it difficult and potentially dangerous to the animal to attach identifying objects on the external body surface. Because cetaceans are widely and relatively sparsely distributed, they are difficult and expensive to capture and

are essentially impossible to anesthetize in the field for surgical practices. Those cetaceans that live entirely in the oceanic environment pose special problems concerning longevity and decomposition of materials for tags and marks. The problems of capture and handling obviously become more difficult as the size of the cetacean increases.

Despite these overwhelming obstacles, the marking and tagging of cetaceans has long been recognized as the only way to gain insight into the unknown aspects of their life history. There are three generalized methods of recognizing individual cetaceans: 1) natural markings, 2) static tags, and 3) sonic and radio tags. Each method will be discussed and evaluated especially in light of their applicability to the large cetaceans.

Natural markings

Since early times people have bsen able to identify individual animals by their unique markings. Early whalers, for example, knew of distinctively marked or anomalously colored whales like the famous all-white bull sperm whale (Physeter macrocephalus) after which the novel Moby Dick was patternsd. Researchers today use natural markings and unusual appearances to identify individuals and monitor their behavior and movement. Pictorial catalogues, for example, have been compiled of gray whale (Eschrichtius robustus] markings (Swartz and Jones 1980; Darling 1977), humpback whale (Megaptera novaengliae) fluke patterns (Kraus and Katona 1977, 1979; Lawton et al. 1980), and killer whale (Orcinus orca) dorsal fin shapes and coloration patterns (Balcomb 1978, 1980) . One of the major questions regarding this method of identification is the reliability and longevity of recognizable markings or deformities.

Available results indicate that identification is possible in most cases over a period of at least a few years and thus valuable data can be gathered about site tenacity over seasons as well as short term migration and home range, social interactions, activity patterns, and habitat use. The main drawbacks of this system are the requisite high labor intensity for data acquisition and the small area of possible coverage. Thus, the limited availability of large, cheap labor pools and local concentrations of cetaceans with a large portion of identifiable individuals often preclude such studies.

Static Tags and Marks

Whalers before the turn of the 20th century occasionally found old harpoons imbedded in the tissues of freshly killed whales, evidence of a previous and unsuccessful hunt. From reports of these harpoons, cetologists conceived of marking whales with labeled harpoons as a means of gathering information on migrations, size of stocks, and effects of exploitation by the whaling industry. Following a successful experimental tagging cruise in 1912/33, an extensive tagging program was underaken by the British Discovery Investigations using 23 cm-long metal tubes fitted with a ballistic head. These marks, which became known as Discovery tags, were fired from a 12-gauge shotgun into the flesh of the whale. Later, marks were also made for smaller whales and were shot from a 410-gauge shotgun. Each tag was labeled with a serial number and an address for return. A reward was offered for receipt of the tag along with vital information concerning the animal and its taking. Although the Discovery Committee discontinued its involvement in this marking effort in 1939, Discovery-type marking

continues today by agencies in many whaling countries (for review see Brown 1978).

It was not until the 1960's, when interest in cetacean studies greatly increased, that investigators began to experiment with methods of tagging and marking which did not depend for their success on the killing of the animal. As a consequence, a variety of externally visible tags and marks were developed to give the investigator a temporary or permanent record of the identity of individual cetaceans.

Because some porpoises and dolphins often ride the bow pressure wave of boats and ships, they are relatively easily captured or tagged from a moving vessel. In recent years, at least three types of spaghetti streamers and five types of dorsal fin tags or marks have been placed on small cetaceans.

The spaghetti streamers initially tested on cetaceans by Nishiwaki et al. (1966) and Sergeant and Brodie (1969) are generally placed just forward of the dorsal fin, a bit to either side of the midline of the back. These tags can be attached to free-ranging animals with a pole applicator (Evans et al. 1972) or crossbow (Kasuya and Oguro 1972) and do not require capture. The tag consists of a stainless steel barb which penetrates through the blubber just into the muscle; a stainless steel or monofilament leader which is attached to the barb and passes out through the skin; and an attached streamer which may be a color-coded extension of the leader or a wide, flat strip of tough plasticized material which trails along the animal's body. Spaghetti tags are numbered and often labeled with an address for return. Because of their small size, the labels cannot be seen on a free-ranging dolphin, even at close range, and specific information can only be obtained when a tag is examined closely on a captured animal or extracted from an animal, usually postmortem. Color coding, however, can often be recognized from a distance and may provide critical information concerning the date and location of tag placement and subsequent movement of the animal. Despite early success with spaghetti tags (Perrin et al. 1979), extensive testing showed that tag entry wounds did not heal which resulted in high tag loss rates and led the National Marine Fisheries Service (NNFS) to discontinue their use for studies in the eastern tropical Pacific (J .C. Jennings, NMFS Southwest Fisheries Center, La Jolla, CA 92038. Pe rs. commun.).

When investigators need more specific and longer-term information shout the porpoises and dolphins being studied, they may ha required to capture the animal and apply more readily visible tags and marks with individual coding. The dorsal fin is generally chosen as the site for tag/mark placement, since it is the most prominent and easily observed portion of a surfacing cetacean and is thought to he more durable than other potential sites (Evans et al. , 1972). Small triangular wedges clipped out of the tough connective tissue on the trailing edge of the dorsal fin have facilitated identification of individual cetaceans in some studies. Alternatively, button or disc tags are placed near the center of the dorsal fin and are held on both surfaces by a central bolt which passes through the fin (Evans et al. 1972), and rectangular visual tags are held in place with two bolts (Irvine and Wells 1972). The smaller Jumbo roto tags, a type of cattle ear tag, pivot On a single s tud which passes through the trailing edge of the dorsal fin (Norris and Pryor 1970). Finally, flag tags, which also pivot on their leading edge, have been tes ted in captivity (Evans et al. 19791, hut these larger tags

have not, at this writing, been used in the field. The tags mentioned ahove have characteristic symbols or alphanumeric designations that allow individual identification at varying ranges depending on their size.

Freeze brands, symbols and alphanumeric designations applied to skin tissue with irons which have been cooled in liquid nitrogen or dry ice and alcohol, have proven effective as permanent marks which are highly visible at moderate ranges (Cornell et al. 1979; Irvine and Wells 1972). These marks have heen placed on the back of small cetaceans (for aerial observers) or on the dorsal fin (for surface observers) causing no apparent discomfort to the animal. Irvine et al. (1979) report a longevity of at least four years on a bottlenose dolphin (*Tursiops truncatus*) and Wells (pers. commun.) more recently reports over five years from the same dolphin population.

During the mid 1970's a great deal of research went into tag and mark development for population studies of the small cetaceans taken incidentally by the tuna fishery in the eastern tropical Pacific. Flow tank and live animal tests provided extensive information on materials and designs including: disc tags, rototags, tail stock bands and streamers, spaghetti streamers, hutton tags, surveyor's tape streamers, dorsal fin clips, dorsal body clips, fin clip saddles, tetracycline tooth deposit marking, tatooing, and freeze branding (National Fisheries Engineering Laboratory 1978; Evans et al. 1979). Despite these exhaustive studies, no optimum static tag has been successfully field tested.

The methods described above have been utilized on a variety of smaller cetaceans. However, due to the obvious difficulties of handling the larger whales, only remote application of tags and marks is practicable. To date, only spaghetti tags (Norris et al. 1976), streamer tags (Mitchell and Kozicki 1975; Rice et al. 1979), paint and freeze branding have been tested in external marking of large whales. Because the life expectancy of streamer tags is so short and the probability of resighting so poor, only sporadic effort has gone into adapting these methods to whales and the results of such programs have been equivocal (Brown 1970). Paint marking, tested by the senior author on California gray whale barnacles after unsuccessful tests on the skin of porpoise by Watkins and Schevill (1976), failed to leave a distinguishing mark after the first submergence, and the freeze brand applied to the released captive gray whale, Gigi, was resighted only once after early contact was lost (Evans 1974).

Sonic Tags

Leatherwood and Evans (1979) summarized the developmental work in applying acoustic tracking devices to cetaceans as follows:

"Early attempts employed acoustic tracking devices developed for the study of fishes. Schultz and Pyle (1965) attempted to attach acoustic transmitters mounted on shallow harpoon heads to California gray whales. Payne (1967, Rockefeller University, pers. commun.) similarly attempted to track humpback whales using acoustic devices. In 1967-1968 one of us (Evans) tested the potential use of sonic transmitters attached by a suction cup to a captive *Tursiops truncatus* (unpublished data). None of these attempts met with any success. The primary problems identified were that 1) ranges obtainable were unacceptably short; 2) transducers, both transmitting and receiving, were inadequate; and, importantly for

future approaches, 3) the projectors used frequencies that fell within the hearing ranges (e.g., see Johnson 1966) of these highly acoustic animals. There were significant problems in all these cases with successful attachment and operation of the transmitters. But even if these technical problems had been overcome, it is highly questionable whether data obtained from these systems could have represented "normal" behavioral patterns for the tagged animals.

Even Kanwisher (1978) who reports the successful telemetering of physiological data from unrestrained porpoise muses that "The possibility also arises that, upon realizing they are listening to their own heartbeat, the animals will be fascinated and vary the rate for their own amusement." Watkins (1978) decided early in his cetacean tracking development program not to use sonic devices on these acoustically sensitive animals. A. Blair Irvine (National Fish and Wildlife Laboratory, Gainesville, FL 32601. Pers. commun.) found while using sonic pingers to study the movements of manatees that ranges were so short (about 400m) that if a tagged animal were ever lost they were highly unlikely to relocate it, even in the confines of the St. Johns River. Irvine also found sonic signals to be sharply confined within a thermal plume and reduced to 30 m reception within the plume. These factors combined with the highly unpredictable sound paths of the oceans, suggest that it is unlikely that any future development in acoustic tracking will produce a system capable of tracking free-ranging cetaceans, except for short distances and time spans.

Radio Tags

Cetaceans spend 85% to 95% of their life underwater, move during the night as well as the day, and often vanish from the watchful eye of an observer, even though they may be clearly marked or tagged. The development of tracking devices for whales and porpoises has thus greatly aided investigators in studying the life history of these animals. For a comprehensive review of tracking systems see Michelson et al. (1978) and for one of radio telemetry see MacKay (1970). In 1961, Shevill and Watkins (1966) began development of a radio transmitter for right whales, Eubalaena glacialis, based on the design of the early discovery tag marks. Although the investigators were unsuccessful in tracking whales with these early transmitters, they did serve to show the feasibility of the attachment of radio transmitters to large cetaceans. During this same time period, other investigators (Evans and Sutherland 1963) were also considering the use of telemetry in the study of marine animals. Between 1967 and 1971, Evans (1971), in conjunction with Ocean Applied Research (OAR), developed a small radio beacon that could be attached to porpoises utilizing existant high frequency (HF), citizen band technology. Because of their short surface times, it was immediately evident that automatic direction finding (ADF) capabilities were essential to the successful tracking of free-ranging cetaceans, and so an ADF was developed by OAR for use in the HF band range (Martin et al. 1971).

There followed two basic methods of attaching radio transmitters to arge cetaceans: animals were captured and physically restrained n some manner so that a radio transmitter could be attached, and radios ere attached by various remote methods. In the former case, Norris ttached OAR radio transmitters to gray whale calves with flexible

elastic harnesses in Baja California and successfully tracked them for up to four days (Norris and Gentry 1974; Norris et al. 1977); Evans (1974) attached a radio transmitter to a yearling gray whale with sutures in southern California and tracked that animal sporadically along the California coast; and Erickson (1978) attached a VHF radio transmitter to the dorsal fin of killer whales by using stainless steel pins and tracked the animals intermittently in Puget Sound, Washington for five months. Watkins and Schevill continued their remotely implantable whale beacon testing and development program in conjunction with OAR through the 1970's (for a review of this development program, see Schevill and Watkins 1966; Watkins and Schevill 1977; and Watkins et al. 1980). Throughout the developmental stage of this radio tag, various design changes have been made, but the concept of a stainless steel shaft implanted within the body of the whale with only the antenna exposed has remained constant. These radio transmitters have been implanted in a number of species of whales and have evolved with each testing. Ray et al. (1978) tagged and successfully tracked fin whales in the St. Lawrence River; Tillman and Johnson (1977) tagged and tracked humpback whales in southeast Alaska in 1976 and again in 1977 (Marine Mammal Division 1977); Watkins et al. (1978; 1981) radio-tagged and tracked finback and humpback whales in Prince William Sound, Alaska; Watkins et al. (1979) tagged and tracked Bryde's whales (Balaenoptera edeni) in Venezuela and Watkins (1981) successfully tagged and tracked fin whales (B. physalus) near Iceland.

In 1978, the longevity of systems for the remote attachment of radio transmitters to free-ranging large cetaceans was limited to 17 days (Watkins et a 1978). Beginning in tha L year, alternate systems were developed to increase the lifespan. Bruce Mate, working with Telonics, Inc., of Mesa, Arizona, designed and tested an umbrella stake attachment with curved tines that penetrated the skin about 7 cm and flared on entry. These VHF transmitters lay on Lhe surface of the whale and were successfully used Lo track gray whales (Mate 1979). Mate (1980) also developed a similar barnacle radio tag implantable by bow or gun which was also tested successfully on gray whales. Follmann (1900) concurrently developed and tested a VHF radio tag wiLh an attachmen L head tha L toggled approximately 2 inches under Lhe skin and a transmitter and antenna that lay flat along the external surface of the animal. We was, however, unsuccessful in tracking with this system.

At the same Lime that investigators were firs L successfully radio tracking small cetaceans, Craighead et al. (1972) were testing a satellite-linked animal tracking device on free-ranging elk (<u>Cervus canadensis</u>). Although these first tests were hampered by the extreme size and weight of the transmitters and were generally though L Lo he unsuccessful, they led Lo a grea L deal of interes t in the possibility of developing smaller, viable transmitters suit.able for studies on animals as wide -ranging in size and habitat as birds and whales. A series of meetings during the late 1960's and early 1970's defined at grea L length the needs for satellite tracking, the technological gaps at Lhat time, and the priorities for development (Galler et al. 1972; Anonymous 1974). However, it was not. until the Fish and Wildlife Service (Kolz et al. 1978) successfully satellite tracked a polar bear (<u>Ursus maritimus</u>) for over one year and 137)0 km tha t interes t in satellite tracking was

revived. Based on tha t success, the National Marine Fisheries Service embarked upon the development of a satellite-linked transmitter (Jennings and Gandy 1980) for attachment to small cetaceans in the eastern tropical Pacific. This program has met with a numb. -r of problems, both electronic and biological, but successful tests are anticipated in 19 81. Both the pola r hear and the porpoise transmitters remain ton large for general application to marine mammals.

<u>Evaluation and discussion of radio tracking systems</u>

There are currently three basic transmitting and receiving systems and four different types of radio transmitter attachments available for large cetaceans. Woodbridge (1978) discussed another potential animal tracking system using extra low frequencies (ELF), hut its development and use on cetaceans is inadvisable due to excessive power requirements, large size, and possible interference with the whale's hearing and communication. Each of the other systems has its benef i ts and shortcomings and wi 11 he discussed in the following paragraphs.

High frequency (HF) systems (27-30MHz) - The greatest advantage of using high frequency systems for radio tracking at sea is the relatively great theoretical tracking distances attainable from shipboard because HF radio waves tend to follow the curva Lure of the earth and are not blocked by ocean waves. Another advantage is the availability of a relatively efficient. ADF, an essential component of any operational radio tracking program. The major drawback to working at this frequency is the inefficiency of antennas which limits tracking range and, more importantly, necessitates larger radio tags because of the battery demands required to achieve adequate radiated power. Additionally, because frequency scanners or other means of. individual identification are not available at HF, multiple receivers are required to locate more than one transmitter.

The WHOI/OAR radio tag is currently the only attachment/deployment system available in the HF band. The maximum longevity of the latest iteration of this tag is unknown but there was no indication of rejection after nine days in the Iceland tests (WaLkinS 1981). The major advantage of the WHOI/OAR tag is the 30 m deployment range which makes it potentially useable on any species of large cetacean. Retuning of the antenna has solved some of the early problems of reduced range due to poor antenna orientation. Because of the differential movement of tissue layers through which these tags pass, the problems of continuous irritation and subsequent healing difficulties persist.. Considerable practice and marksmanship are essential when using this tag system.

Very high frequency (VHF) systems (148-164 MHz) - Highly efficient antennas are available in this frequency range and the resultant low power requirements permit the use of very small, lightweight radio tags. Additionally, VHF scanning and data processing equipment have been developed to identify individual transmitters and collect telemetry data, and automated data collection and remote station capabilities are already being developed. Another advantage of the VHF frequency is the potential of less noise (the shorter ranges also provide fewer competing signals from a distance. There are, however, two drawbacks to using VHF for tracking at this time: 1) there is no ADF which will work effectively with the low power output from standard VHF transmitters, and 2) surface VHF reception is highly limited to line-of-sight and may be affected by

sea state. There is also some evidence that low-level inversions over cold water mav block VHF propagation entirely for periods of time.

There are currently three possible attachment/deployment systems for VHF transmitters: the barnacle and umbrella stake tags developed by Bruce Mate and the whale tag developed by Erich Follmann. Each of these tags is small and lightweight, but because the transmitters lie on the surface of the whale , they are subject to dislodgement or crushing. The umbrella stske tag has the best antenna orientation of any tag available but attachment is restricted in use to quiescent whales. The barnacle tag can be deployed on moving whales but presently has limited deployment range (5 m in this study) and potentially poor antenna orientation. Although Follmann's tag is less liable to dislodgement and crushing than the other two tags and can be deployed at a greater distance (up to 9.1 m), very poor antenna orientation and detuning due to antenna contact with the whale severely limit the theoretical range of the transmitter in its present configuration. A fourth possibility for tracking whales in the VHF range would involve replacing the HF transmitter and antenna in the WHOI/OAR tag with a VHF transmitter and antenna.

Satellite systems (401. 2MHz) - Satellite-linked systems can track animals and gather data over vast and inaccessible areas at relatively low Cost . As fuel costs rise, this will be an ever increasing advantage over other tracking systems for long term or long distance studies. All satellite animal tracking to date has been accomplished using the Nimbus system, but since the system has passed its operational life expectancy, it is increasingly difficult to be assured of continued operation and reception priority. The newer Argos satellite system offers two location and data collection Satellites, sun-sychronous and polar orbiting which have good global coverage especially in the higher latitudes. The greatest drawbacks to satellite tracking are that no tags are presently available for whales and that some whale species may not surface often enough during certain behavior modes to insure location by the orbiting receivers. Satellite tags should have a relatively long retention time to increase the probability of successful tracking.

In conclusion, it seems clear that the operational tracking of free-ranging large cetaceans is well within the realm of technological feasibility. The method of tagging and tracking will be dependent upon the objectives of a given study and upon the species to be studied. To insure operational systems, the following tests and developments are needed:

1) The development and testing of a VHF-ADF for surface vessels and aircraft.

2) The development and testing of an automated data collecton unit with hard and soft copy capability for HF and VHF.

3) Inclusion of the automated data collection units in remote stations (capable of data storage for up to two weeks) for monitoring coastal species.

4) The development and testing of HF and VHF telemetry capability, initially for environmental monitoring (temperature and depth) followed by physiological monitoring (heart bsat, blood pressure, core temperature).

5) The development and testing of a high-gain, HF-ADF antenna for aircraft.

6) Laboratory and field studies of rejection mechanisms designed to gather data which will suggest developments to increase longevity of tags.

7) The development and testing of an Argos satellite-linked location transmitter.

8) Continued development and testing of attachment mechanisms.

BOWHEAD WHALE TAGGING FEASIBILITY STUDY

Introduction

In June 1978 the Bureau of Land Management (BLM) of the U. S. department of the. Interior entered into an Endangered Species Section 7 consultation with the NMFS to determine the impact of oil and gas resource development in lease-sale areas of the Beaufort Sea on bowhead and gray whales. In August of that year, NMFS recommended studies to BLM that would fill the data gaps identified during the consultation. One type of study recommended was to determine the "timing of movements and offshore distribution of bowhead and gray whales through the proposed lease-sale areas and adjacent waters." Studying the "overall movement patterns of bowhead and gray whales in the Beaufort Sea" was also recommended by NMFS. Although the general pattern of migration is known for bowhead whales (Braham et al. 1980; Braham and Krogman 1977; Fraker 1979; Fraker et al. 1978), the specifics of migratory timing, movements, and habitat use are largely unknown and lend themselves to study by radio tracking. With the successful tracking of radio tagged gray whales along their migratory path for up to 95 days (Mate 1979), a test was needed to determine the feasibility of tagging and tracking bowhead whales. In addition to determining the feasibility of finding, approaching, and tagging bowhead whales, this study sought to determine longevity of the tags, effect of the tags on behavior, dive-surface profiles, and movement patterns of bowheads in the vicinity of the northern Alaska Outer Continental Shelf (OCS) lease-sale areas.

Study Area

For these initial tests a study area was chosen which would afford the maximum probability of locating bowhead whales in ice-free waters of the Beaufort Sea, where the animals could be approached easily by surface vessel and tagged without ice nearby on which the whales might dislodge the surface-mounted transmitters. It was also imperative to have an accessible logistical base with an airfield and supplies. After studying whaling and sighting records (Bodfish 1936; Cook 1926; Fraker and Bockstoce 1980; Hazard and Cubbage 1980; Ward 1979) and interviewing researchers who had worked in the Beaufort Sea (H.W. Braham, National Marine Mammal Laboratory, NMFS Northwest and Alaska Fisheries Center, Seattle, WA 98115; M.A. Fraker, LGL Ltd, Vancouver, B.C., Canada V6P 6G5; o.E. Sergeant, Arctic Biological Station, Fisheries and Marine Service, Ste. Anne de Bellevue, Quebec, Canada, H9X 3L6; and I. Stirling, Canadian Wildlife Service, Edmonton, Alberta, Canada, T5K 2J5. Pers. commun.) the village of Tuktoyaktuk was chosen as the logistical center because of the high probability of locating concentrations of whales between Cape Perry on the east and Herschel Island on the west. The relocation area encompassed the entire Beaufort Sea from approximately 125°W near Cape Perry, Territories, Canada to 155°W near Point Barrow, Alaska, and offshore to approximately 72°N (Fig. 1). This area included the "north slope" OCS lease-sale area from 146°W to 154°W .

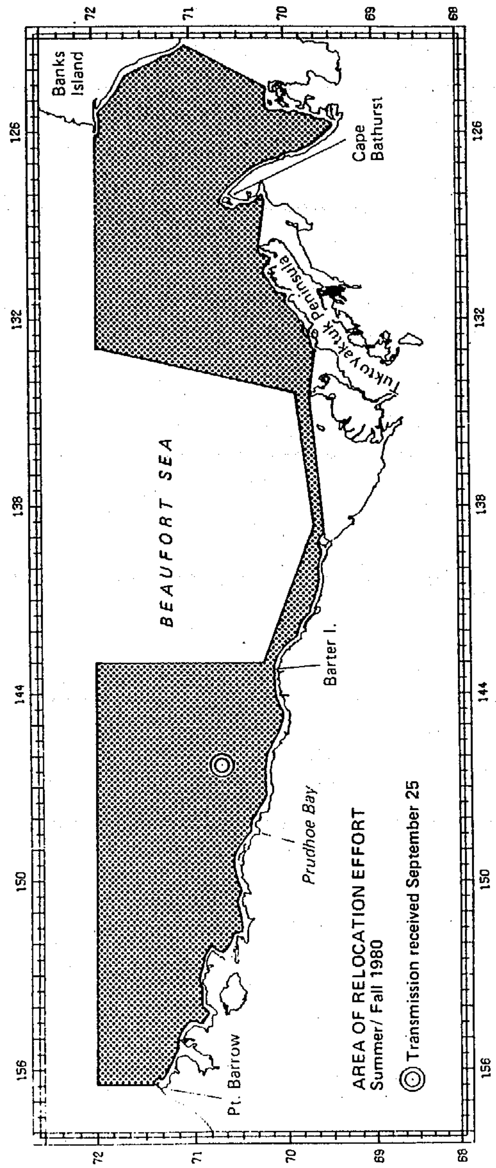
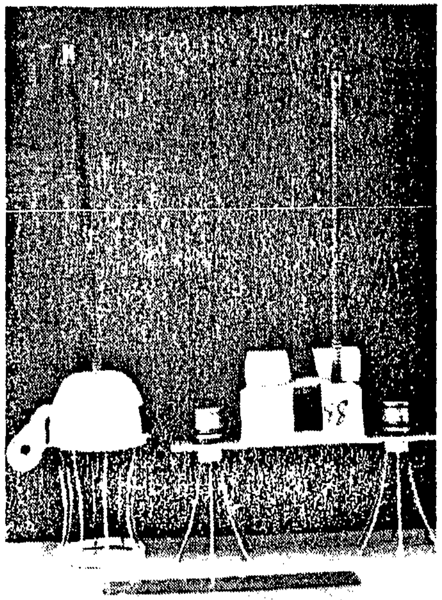
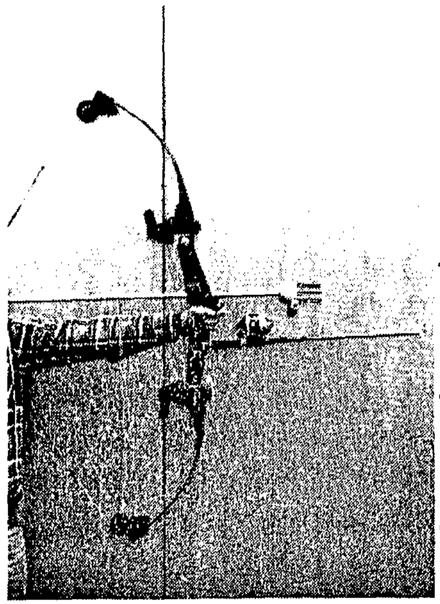
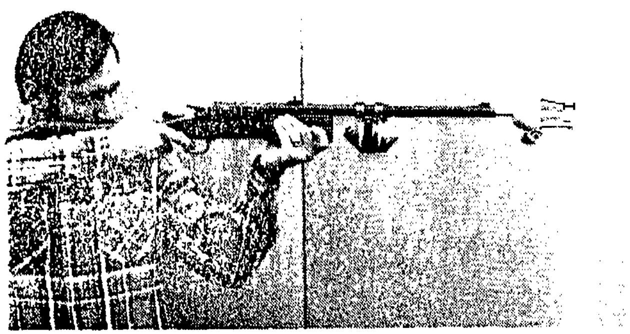


Figure 1. The bowhead whale tagging study area including the relocation effort during the summer/fall 1980.







igure 2 (top left)
adio transmitter tags used for tagging
wwhead whales: barnacle tag, left;
nbrella stake tag, right.

Figure 3 (bottom)
Modified drug immobilization rifle used in deployment of barnacle tags.

Figure 4 (top right)
Compound bow equipped with a retrieval reel tested for use in deployment of barnacle tags.

Field Preparation

Of prime importance to this study was the testing, alteration, and fabrication of the radio tags. The tag types chosen for this experiment were developed and thoroughly field tested by Bruce Mate on gray whales (for description see Mate 1979 and Mate 1980). These barnacle and umbrella stake tags (Fig. 2) had, however, never been tested on any other cetacean species. Therefore, frozen blubber blankets were acquired from bowhead whales taken in the annual Eskimo harvest; and although the blubber samples did not accurately portray in vivo tissue responses, tests were undertaken to simulate the effects of the two tags on bowhead tissue and the effectiveness of the holdfasts relative to gray whale tissue.[1] The tags were tested and altered and retested over a 6 day period with the following results:

Barnacle tag - The maximum distance for proper deployment and antenna orientation of barnacle tags was initially calculated to be approximately 5 m. Thus, all test tags were fired from 5 m into the available pieces of bowhead blubber which included the fascia but not the skin and were extracted with a spring scale to give a relative indication of holding power of various test configurations. Video tape recordings were made of test firings to allow instant reevaluation. Initial tests showed that deployment by a drug immobilization rifle (Zulu Arms, Omaha, Nebraska; Fig. 3)[2] was superior in speed and accuracy to deployment by

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1 Special thanks for the blubber samples to Tom Albert, Erich Follman, Gordon Jarrell, and the Eskimo whaling captains who gave them tissues.

2 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

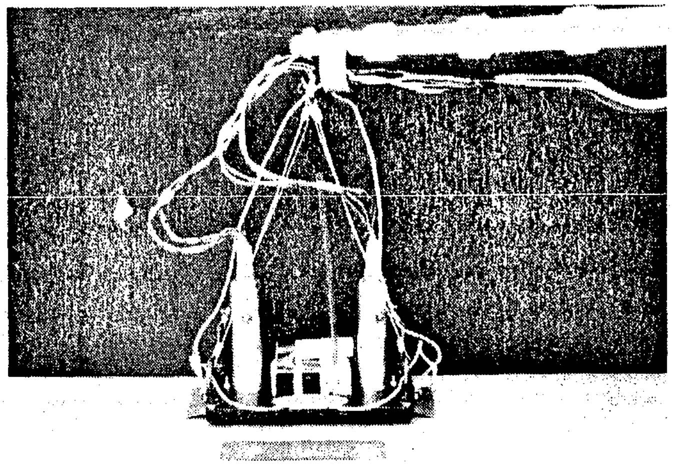

Figure 5
Module used for deploying umbrella stake tags on whales.

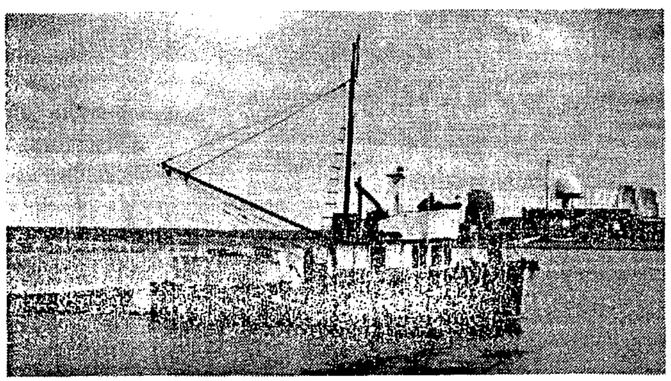

Figure 6
The *Pressure Ridge*, a 48 foot purse seiner, was used by the tagging crew between August 3 and August 19.

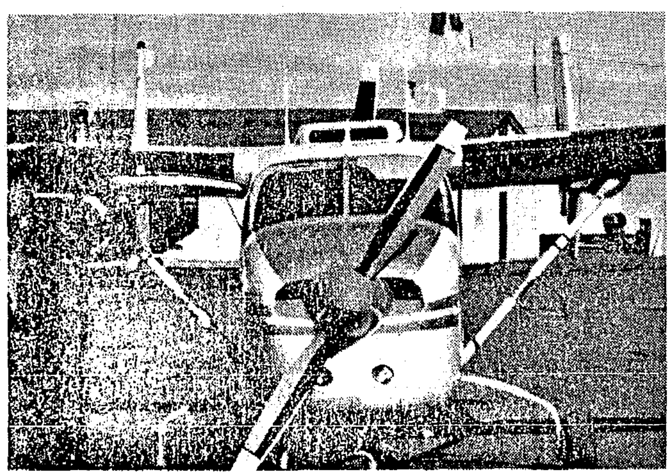

Figure 7
Charter aircraft used for relocating tagged whales. Receiving antennae were easily mounted on wing struts before flights.

a compound bow (Bear Archery, Gainesville, Florida; Fig. 4), 'and that the new teflon fine retaining rings worked well. They also suggested the following modifications and further tests: 1) place barbs on the tines to add greater holding power, 2) further deform tines before loading to create more flare, 3) file base of tines to help them further deform upon entry, and 4) dissect out shots to determine deformation in situ. Further test shots and dissection indicated that the addition of barbs and the further deformation of the tines before loading contributed significantly to the holding power of the tags and that filing the bases of the tines made no difference. Thus, the barnacle tags for the field experiments were fabricated with flaring tines, barbs, teflon retaining rings, 7.5 cm by 1 m Saflag visual streamers (Safety Flag Co. of America) and the s2B5 transmitter and antenna (Telonics, Inc.) tested by Mate. The streamers were designed to aid in visual relocation and to provide a standard for determining the length of the tagged whale by aerial photogrammetry.

Umbrella stake tag - Early tests of this tag deployment system (see Fig. 5) indicated that the stakes were not seating against the base plate nor de forming when entering bowhead tissue as they had on gray whale tissue. These tests suggested the addition of barbs to the umbrella stake tines to increase holding power and further testing to determine if the stakes were not seating because of bounce back or because of lack of power for penetration. When barbs were added to the stake tines they uniformly seated on the baseplate and required well over twice as much force to dislodge. Subsequently, barbs were added to all stakes for the field exercises.

The receiving system was identical to that used by Mate (Telonics TR-2 receiver, TS-1 scanner, TDP-2 processor, and OF receiver). However, rather than rely on individual frequencies for unique identification of each tagged animal and run the risk of missing a signal from a tag during a frequency scan, 15 transmitters were tuned to one frequency and the individual transmitter was identified by the time between pulses. The remaining three transmitters were tuned to another frequency and used as backups.

The success of the tagging project depended on our ability to find and approach bowhead whales at quite close range and then to radio track them from the surface and from the air. The 48 ft motor vessel, Pressure Ridge (Fig. 6) was chartered for the study. People familiar with bowhead whales in the Arctic (J. J. Burns, Alaska Department of Fish and Game, Fairbanks, AK 99701; R. Silook, Gambell, AK 99742; and V. Steen, Captain, Pressure Ridge, Tuktoyaktuk, Northwest Territories, Canada, XOE 1C0. Pers. commun.) felt that whales could be approached in an aluminum boat with outboard motor from the Pressure Ridge to within 5 m for tagging with the barnacle or umbrella stake tags. A 16 ft Lund Aluminum heat was purchased (and shipped to Tuktoyaktuk) with a variety of outboard motors and was mortified for two sets of oars so that various methods of approach could be tested. A satellite navigation system was leased for Pressure Ridge to assure accuracy of sighting locations and vessel position.

A Grumman Goose, N780, already surveying for bowhead whales in the Beaufort Sea under contract to BLM, was modified to carry two, side-looking, high gain, two-element yagi antennas and two whip antennas for direction finding (DF) capability. The Grumman N780 was made available periodically through the summer in the eastern Beaufort Sea and then again in the fall in the central and western Beaufort for reconnaissance and for radio tag relocation effort. In addition, removable mounts for side-looking, high gain antennas were fabricated for aircraft of opportunity and small charter aircraft (one set for high wing Cessnas (Fig. 7) and one set for Twin Otters).

In order to provide photodocumentation of the research and to provide the field party with a very useful tool for instantaneously evaluating research protocol and whale behavior, a portable video tape unit was tested for field use. Video taped sequences could be used to compare normal bowhead behavior to the behavior of tagged whales, to document tag condition over time, and to record whale reaction to tagging. Still photos were taken of all phases of preparation and field activities.

Field Activities

Beginning 17 July, the Office of Aircraft Services of the U. S. Department of the Interior in Anchorage modified Grumman N780 for aerial radio tracking. After installation and testing of the antennae and receiving equipment in Anchorage, aerial surveys for bowhead whales were flown enroute to Tuktoyaktuk along the Alaska and Canadian Arctic coasts. Nine gray whale, six walrus (*Odobenus rosmarus*) and two white whale

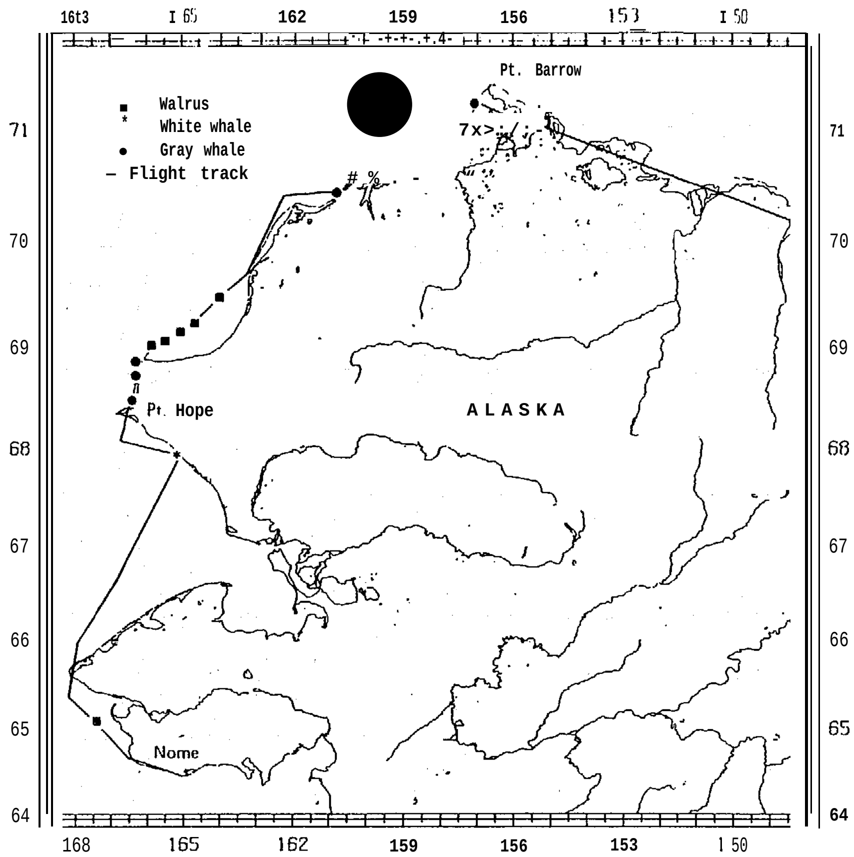

Figure 8. 20 July coastal survey from Nome to Point Barrow. No bowhead whales were sight ed on this flight. *

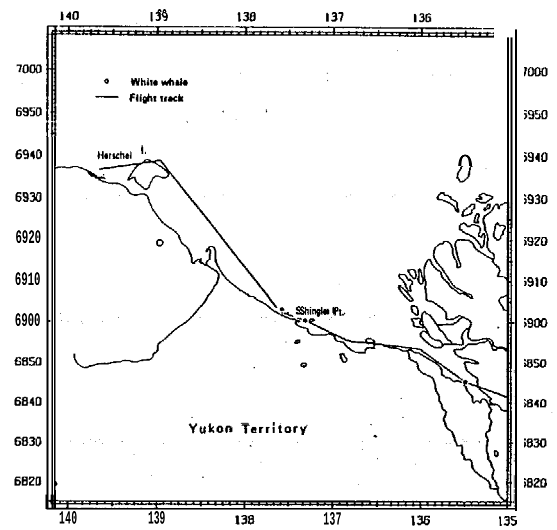

Figure 9. 21 July coastal survey from Herschel Island along the Yukon coast to the Mackenzie River. Hundreds of beluga whales were sighted in the vicinity of Shingle Point. *

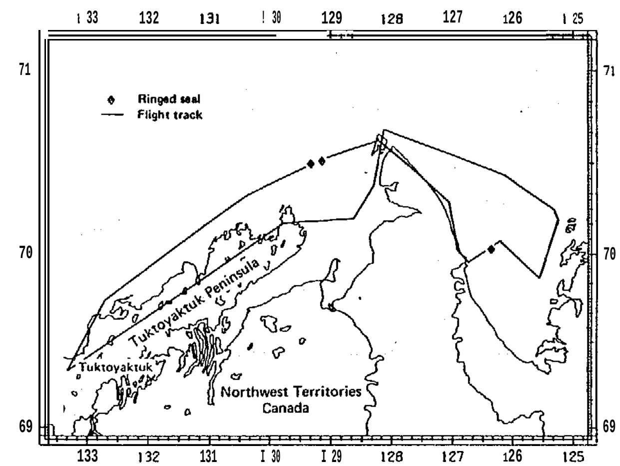

Figure 10. 22 July survey along the Tuktoyaktuk peninsula into Liverpool and Franklin Bays. Note that no bowhead whales were sighted on this flight. *

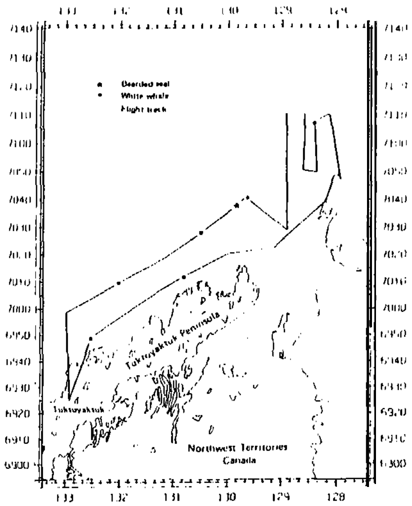

Figure 23 July survey along the Tuktoyaktuk Peninsula and northwest of Baillie Islands-two areas of historical bowhead whale abundance in early August. Unconfirmed bowhead sighting near beluga whale sighting at 70° 37.5'N, 129° 50.6'W.*

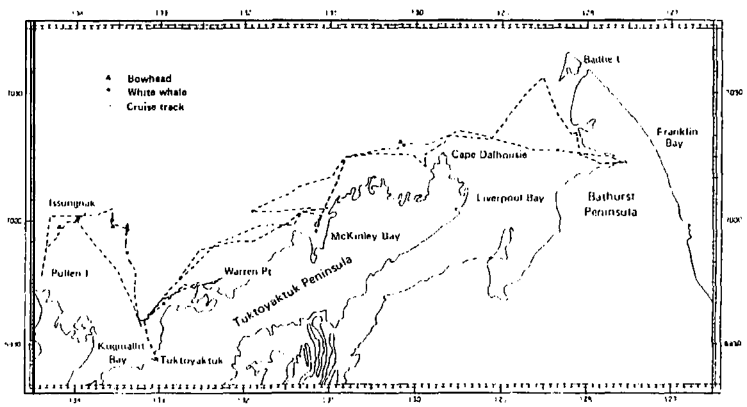

Figure 12. Cruise track of the Pressure Ridge from 3 August through 11 August, including sightings of bowhead and beluga whales. Areas to the east of Tuktoyaktuk were searched between 3 and 7 August and those to the west between 9 and 11 August. The bowhead sighting shown at 70° 18.0'N, 130° 12.3'W was unconfirmed.*

(Delphinapterus leucas) sightings were made along the west coast of Alaska on July 20 (Fig. 8) and two large schools of white whales were sighted in Canadian coastal waters on July 21 (Fig. 9); no bowhead whales were sighted on either day of the survey. Further surveys were flown on 22 and 23 July to locate bowhead whale concentrations in the eastern Beaufort Sea. In 7 1/2 hours of flight along the Tuktoyaktuk Peninsula, Baillie Islands, and in Liverpool and Franklin Bays, only one possible sighting of a single bowhead (70°37.5'N, 129°50.6'W) was made in addition to four sightings of ringed and bearded seals and six sightings of 33 white whales moving predominantly southwest toward the Mackenzie River Delta (Figs. 10, 11). Before Grumman N780 returned to Alaska on 24 July, all radio receiving systems were tested and calibrated, and the survey crew was given instructions in the use and care of the aircraft receiving equipment.

On August 3 the charter vessel, Pressure Ridge, left Tuktoyaktuk Harbor completely outfitted for 15 days at sea, searched for bowhead whales reported along the Tuktoyaktuk Peninsula and then continued on to the vicinity of Baillie Islands where whaling records indicated the abundant occurrence of whales in early August (Fraker and Bockstoce 1980). The scientific party spent 4 days searching as far east as Franklin Bay and recorded only one unconfirmed bowhead whale sighting along with 2 sightings of ringed seals (51 animals) and 4 sightings of bearded seals 4 animals Fig 12).

The Pressure Ridge returned to Tuktoyaktuk to solve radio communication problems and to determine the location of whale concentrations reported by Mark Fraker ("Effects of Human Disturbance" study, LGL, Ltd.). Between 9 and 11 August a total of 34 bowhead whales were encountered on 5 occasions and in 2 cases tagging was attempted and abandoned after a short time because of heavy fog (Fig. 13). A school of about 70 white whales was sighted on 9 August heading west toward the McKinley 'Delta. Bowhead whales encountered during this time were moving quite rapidly and could only be tagged with the ballistically deployed barnacle attachment, since umbrella stake tags can only be attached to relatively sedentary whales. Bowheads were approached in the aluminum skiff at high speed as was advised by native hunters, but each time the skiff came within about 30 m, the whales sounded. In no ins tance was it possible to maneuver within tagging distance. Foul weather then forced the Pressure Ridge hack to Tuktoyaktuk Harbor on 11 August.

On 13 August Grumman N780 returned to Tuktoyaktuk to survey the nearshore waters *am-l to* determine the distribution of whales. In 22 sightings 30 whales were counted between Warren Point and Cape Dalhousie (Fig. 13) during systematic surveys f lawn parallel to the Tuktoyaktuk Peninsula on 14 August. subsequently, survey and search flights were flown (Figs. 14-23; Table 1) to determine any change in distribution and to direct the tagging team to areas of maximum whale concentration. While in Tuk toyak tuk awaiting good weather, a barnacle tag was tested on a white whale kil led in the Eskimo fishery. The tag deployed very well and is recommended for radio attachment for that. species.

Bad weather conditions prevented any work from the Pressure Ridge between 16 and 19 August. The aircraft survey crew made 88 sightings of 161 bowhead whales during this time (Figs. 14, 15) . On 19 August the vessel charter was terminated by mutual agreement and the tagging Learn

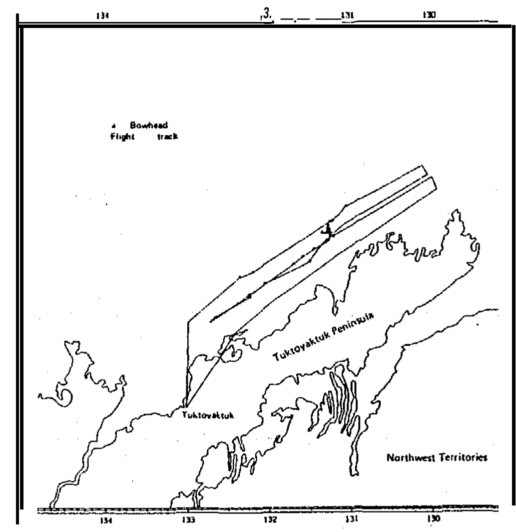

Figure 13. The 14 August survey flown in the Grumman Goose. There were 22 sightings of 30 bowhead whales on this flight.

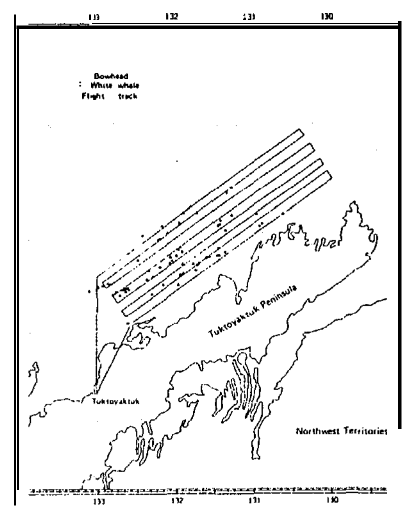

Figure 14. 18 August aerial survey along the Tuktoyaktuk Peninsula resulted in 28 sightings of 47 bowheads.

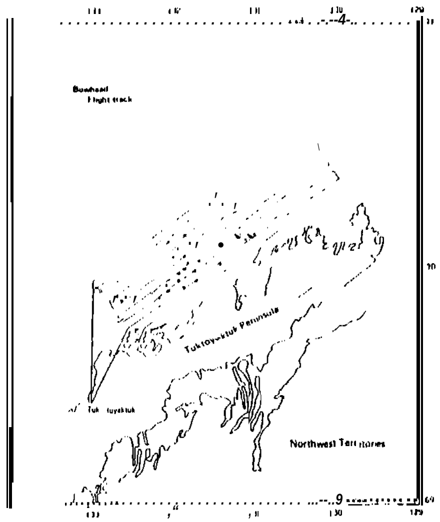

Figure 15. 19 August aerial survey logged 60 sightings of 114 bowheads and 14 belugas in three sightings.

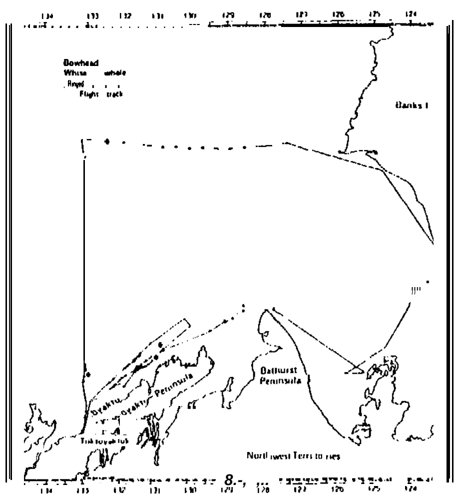

Figure 16 20 August aerial survey designed to determine the distribution of bowheads in open water of the eastern Beaufort Sea. There were 46 sightings of 157 bowheads, 18 sightings of 194 beluga, and four sightings of five ringed seals on this flight.

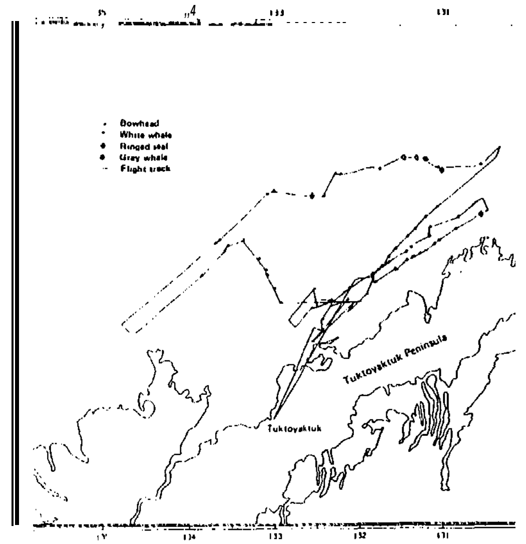

Figure 17. 21 August survey along the Tuktoyaktuk Peninsula showing the distribution of 59 sightings of 245 bowheads, three sightings of 49 belugas, six sightings of 113 ringed seals, and one gray whale sighting. Tagged bowhead number 137 was monitored for 1 1/2 h by the Grumman Goose before returning to Tuktoyaktuk for fuel.

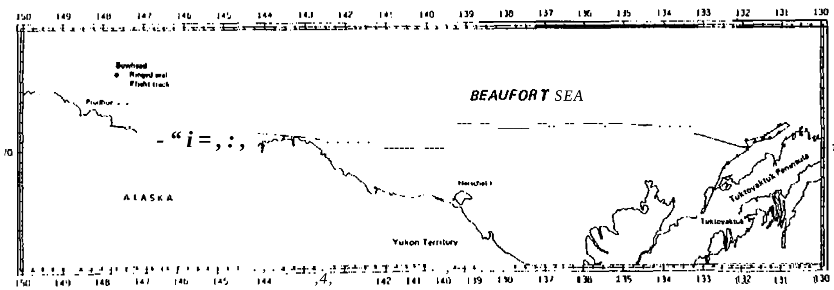

Figure 18. On 22 August, sixteen sightings of 73 bowheads were made along the Tuktoyaktuk Peninsula and three sightings of 12 whales were made en route to Deadhorse, Alaska.

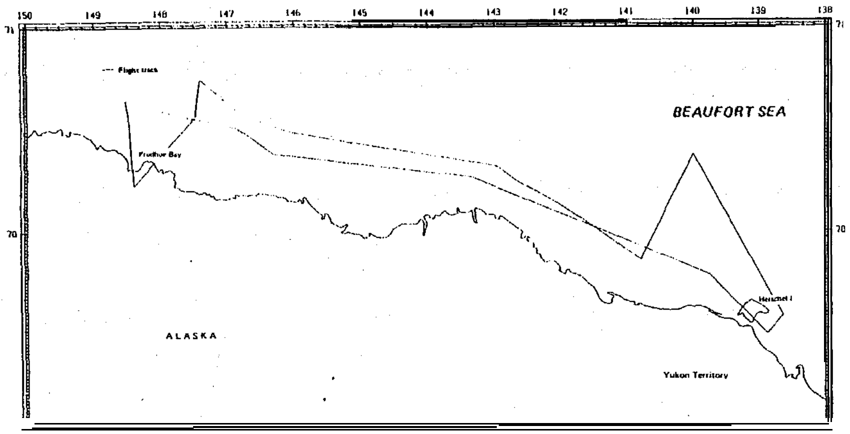

Figure 19. 30 August survey along the Alaskan and Yukon Coasts. Deteriorating weather conditions prevented surveying efforts to continue east to Tuktoyaktuk. No whales were sighted between Prudhoe Bay and Herschel Island.

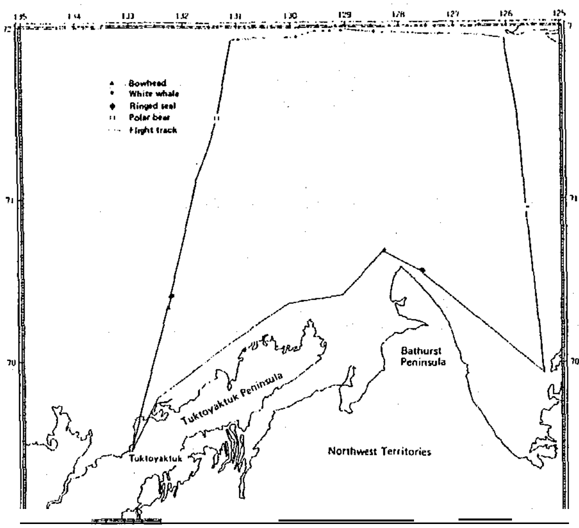

Figure 20. Broad area covered by 31 August survey of the eastern Beaufort Sea and Amundsen Gulf in an attempt to define fall bowhead distribution and relocate tagged whales. There were six sightings of 12 bowheads, seven sightings of at least

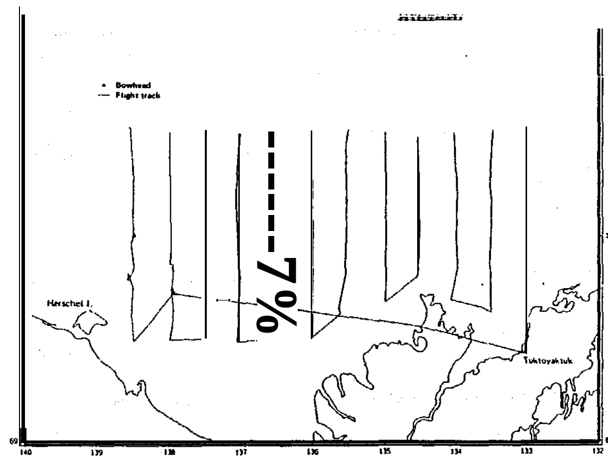

Figure 21. 3 September survey and radio tag relocation flight north of the Mackenzie Delta from the Tuktoyaktuk Peninsula to Herschel Island. Four sightings of eight bowheads were made on this flight.

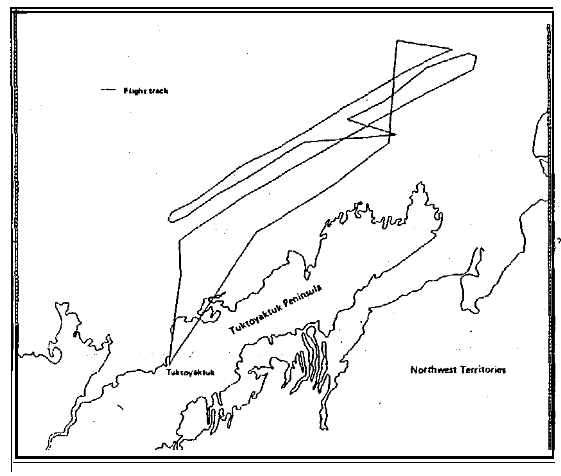

Figure 22. 4 September survey off the Tuktoyaktuk Peninsula searching for whale concentrations and radio tagged whales. No whales were sighted

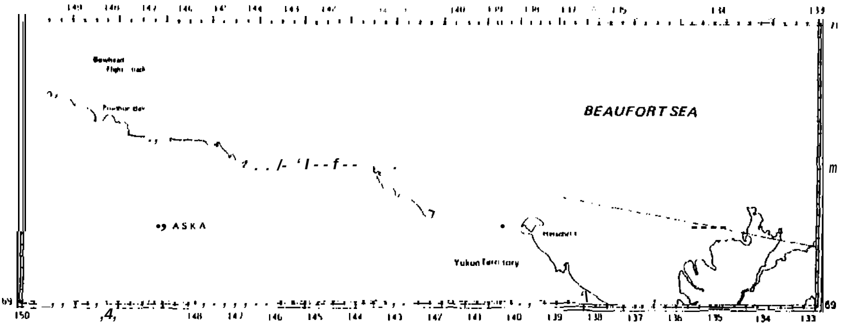

Figure 23. 4 September survey from Tuktoyaktuk to Prudhoe Bay, Alaska. There was one sighting of two bowheads.

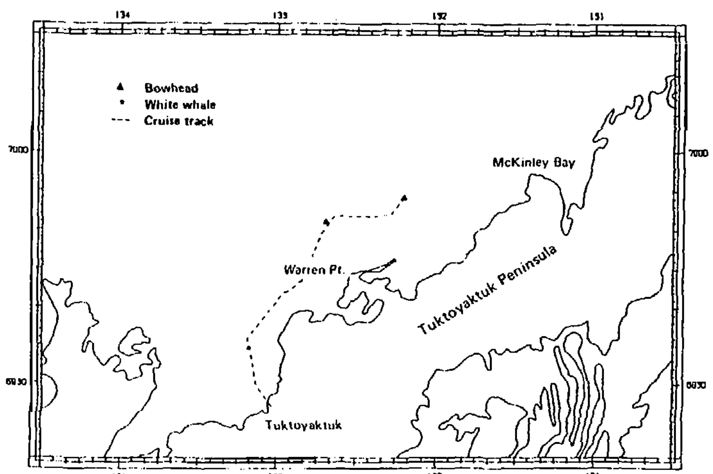

Figure 24. 20 August cruise track of the Ungaluk. Tag number 135 was successfully deployed at 69° 54'N, 132° 12'W.*

ABLE 1. --Sighting data collected by aircraft and shipboard observers in the eastern Bering Sea between 3 August and 12 September 1980.

ate	Platform	Species [1]	Number of Sightings	Number of Animals	Mean Size	Group ± S.D.
ugust 3	Pressure Ridye	BE	1	1	1	± 0
		RS	1	50	50	± 0
		BS	2	2	1	± 0
ugust 4	Pressure Ridge	BO	1	1	1	± 0
		BE	2	2	1	± 0
		BS	1	1	1	± 0
ugust 5	Pressure Ridge		0			
ugust 6	Pressure Ridge	RS	1	1	1	± 0
		BS	1	1	1	± 0
ugust 7	Pressure Ridge		0			
ugust 9	Pressure Ridge	BO	3	24	8	± 10.4
		BE	1	70	70	± 0
ugust 10	Pressure Ridge	90	1	1	1	± 0
ugust 11	Pressure Ridge	BO	1	9	9	± 0
ugust 14	Grumman N780	no	22	30	1.36	± 0.95
ugust 16	Pressure Ridge		0			
ugust 18	Grumman N780	BO	28	47	1.69	± 1.02
ugust 19	Grumman N780	BO	60	114	1.90	± 1.27
		BE	3	14	4.67	± 1.53
ugust 19	Pressure Ridge		0			
ugust 20	Grumman N780	BO	46	157	3.41	± 4.95
		BE	18	194	10.78	±12.95
		RS	4	5	1.25	± 0.50
ugust 20	Ungaluk	BO	2	32	16.00	± 5.66
		BE	1	1	1	± 0
		RS	7	13	1.86	± 2.27
ugust 21	Grumman N780	SO	59	245	4.15	± 4.98
		BE	3	49	16.33	±22.37
		Gw	1	1	1	± 0
		RS	6	113	18.83	±15.38

TABLE 1.--Sighting data collected by aircraft and shipboard observers in the eastern Bering Sea between 3 August and 12 September 1980--continued.

Date	Platform	Species[1]	Number of Sightings	Number of Animals	Mean Size	Group ± S.D.
August 21	Ungaluk	80	92	193	2.10	± 3.40
		RS	15	36	2.40	± 1.68
August 22	Grumman N780	80	19	85	4.47	± 5.10
		BS	1	9	9	± 0
August 22	Ungaluk	80	69	92	1.33	± 0.82
		RS	23	24	1.04	± 0.21
August 23	Ungaluk	BO	5	20	4.00	± 6.71
		RS	18	23	1.28	± 0.57
August 24	Ungaluk	so	26	30	1.15	± 0.37
		BE	1	10	10	± 0
		RS	9	11	1.22	± 0.44
August 31	Grumman N780	BO	6	12	2.00	± 1.10
		BE	7	23	3.27	± 2.14
		PB	1	1	1	± 0
Sept. 3	Grumman N780	BO	4	8	2.00	± 0.s2
Sept. 4	Grumman N780	so	1	2	2	± 0
Sept. 12	Skymaster	so	25	37	1.48	± 0.s2
		BE	3	17	5.67	± B.08
		RS	2	51	25.50	±34.65
		ES	1	1	1	± 0
		PB	1	1	1	± 0

1 BO . Bowhead Whale
BE = White Whale
GW = Gray Whale
RS = Ringed Seal
ES = Bearded Seal
PB = Polar Bear

transferred from Pressure Ridge to a shared charter with an NMFS research team aboard the sailing vessel *Ungaluk*.

During the afternoon of 20 August, whales were sighted from the *Ungaluk* in the vicinity of Warren Point along the Tuktoyaktuk Peninsula (Fig. 24) and tagging was attempted from the aluminum boat, again using the outboard motor. Various approach angles and speeds were tested but only one approach came near firing range (about 10 m), and the shot taken with a barnacle tag fell well short of the whale. After 3 hours, fog closed in and further tagging attempts were only possible from the *Ungaluk*. Quiet approach by sail worked well and at 2330 hours (69°54 'N, 132°12 *W) barnacle tag number 135 with a white streamer was placed on a 35 ft bowhead (Fig. 25). The animal had rolled on its side and the transmitter was implanted midway down the left upper body, too low for transmission on each surfacing. When tagged, the whale kept rolling in its sounding dive without changing speed or thrashing flukes. Signals were received. intermittently for 10 minutes and then lost.

Because of the successful tag placement under sail, it was decided to attempt further quiet approaches by rowing the aluminum boat rather than using the motor. On 21 August (for cruise track see Fig. 26) barnacle tag number 137 with a ye 11ow streamer was successfully placed on a 40 f t bowhead whale using the rowing technique (Fig. 25). After the tag implanted, the whale continued to lay at the surface for about 4 seconds, twitched its skin, and slowly swam away. Grumman N780 was surveying in the area (Fig. 20) and was able to receive signals from the tagged animal until it ran low on fuel, about 1 1/2 hours after initial radio contact. The dive-surface data collected at that time from tag number 137 (Fig. 27) was contaminated to an unknown extent by radio

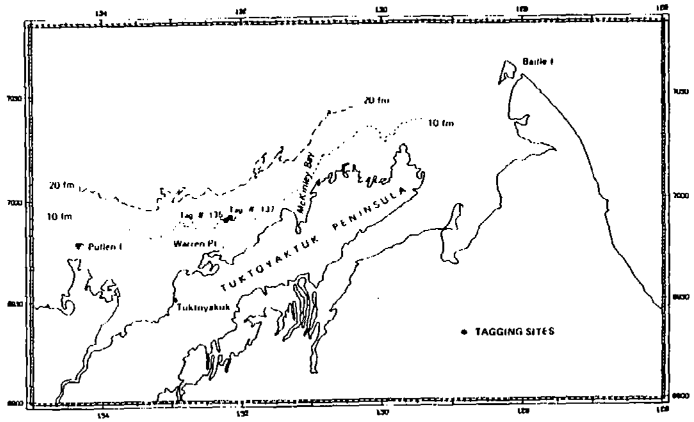

Figure 25. Two bowhead whales were tagged during this study: transmitter number 135 was deployed on 20 August (69° 54'N, 132° 12'W) followed by transmitter number 137 on 21 August (69° 55'N, 132° 11'W).

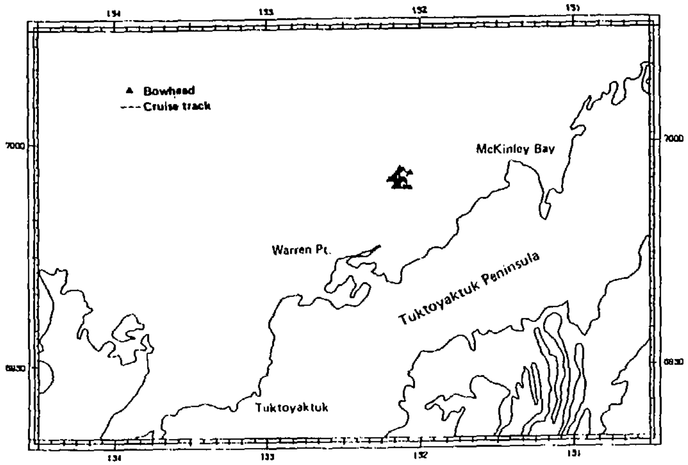

Figure 26. 21 August cruise track of the Ungaluk. Tag number 137 was successfully deployed at 69° 54'N, 132° 11'W.*

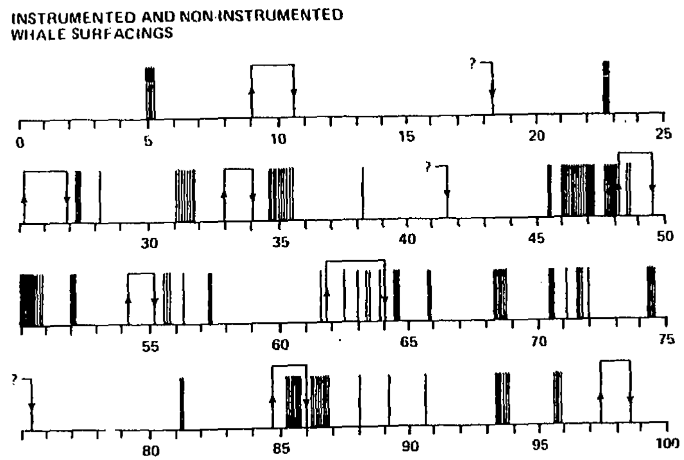

Figure 27. Each single line represents a signal acquired by aircraft from radio tagged whale #137 and lines with arrows represent the dive/surface pattern of a bowhead recognizable from natural markings. Two tags may have been transmitting during this period. Time is indicated along the horizontal axis in minutes.

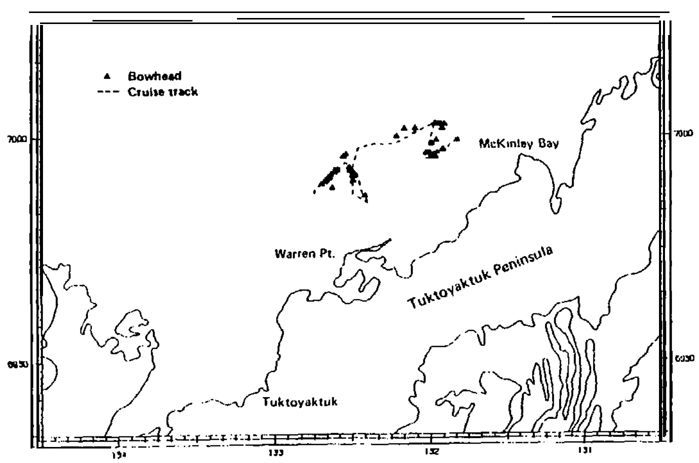

Figure 28. 22 August cruise track and sightings from Ungaluk. Each symbol represents one sighting of one or more animals.

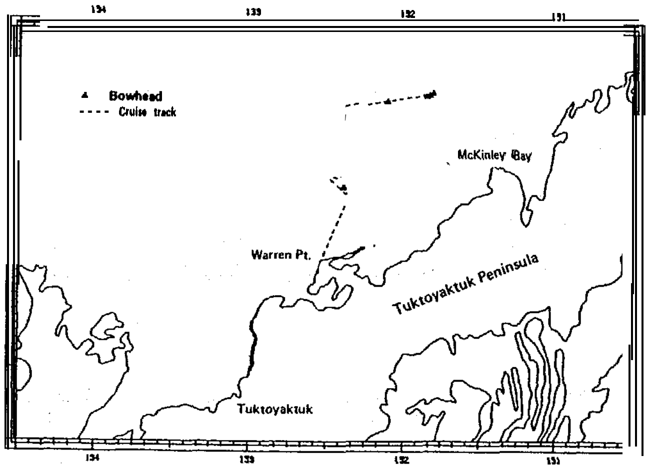

Figure 29. 23 August cruise track and sightings from Ungaluk. Each symbol represents one sighting of one or more animals.

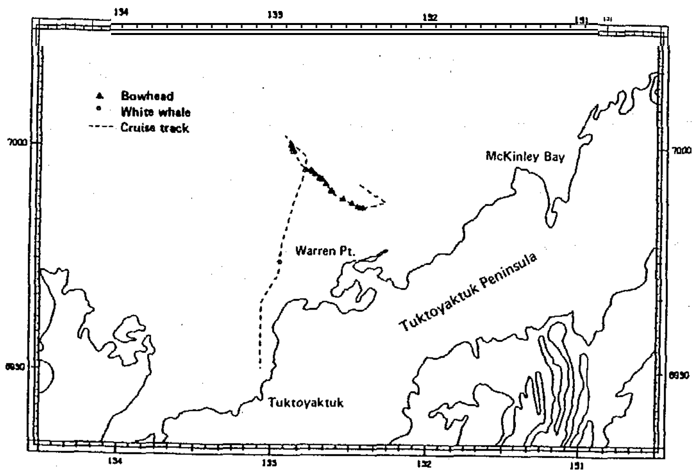

Figure 30. 24 August cruise track and sightings from Ungaluk. Each symbol represents one sighting of one or more animals.

transmissions at the same frequency from Ungaluk and the tagging skiff. The receiving range from the Ungaluk, which should have been 15 miles, had deteriorated since previous tests to less than 2 miles; and by the time faulty antenna connectors were identified and repaired, the whale had disappeared and signals were not received again. Later that day, a barnacle tag shot missed a bowhead at close range. There was no visible reaction to the discharge or to the tag striking the water about 2 m beyond the whale.

On 22 August the aerial survey team searched for the tagged whales and then returned to Alaska. For the next 3 days (Figs. 28-30), the scientific party aboard Ungaluk searched for large concentrations of whales but the bowheads seemed to be spreading out and moving west rapidly. One group of juvenile whales (approximately 30 ft in length) surfaced repeatedly within about 50 m of the aluminum boat, but the skiff was too heavy and awkward to be rowed fast enough to reach them before sounding. However, dive-surface profiles were collected from animals identifiable by natural scar patterns, and one profile was compared to the radio transmissions from tag number 137 (Fig. 27).

Although large numbers of whales were seen along the Tuktoyaktuk Peninsula between 25 and 27 August by LGL and NMFS scientists, the Ungaluk, which had run aground on 25 August, was unfit to return to sea. On 30 August the aerial survey team attempted to fly to Tuktoyaktuk but was forced to return to Deadhorse because of weather. No whales were sighted on that flight between Prudhoe Bay and Herschel Island (Fig. 19). Surveys' conducted aboard Grumman N780 on 31 August and 3 and 4 September indicated that bowhead whales had dispersed from the Tuktoyaktuk Peninsula (Figs. 20-23) and no large concentrations were found (10

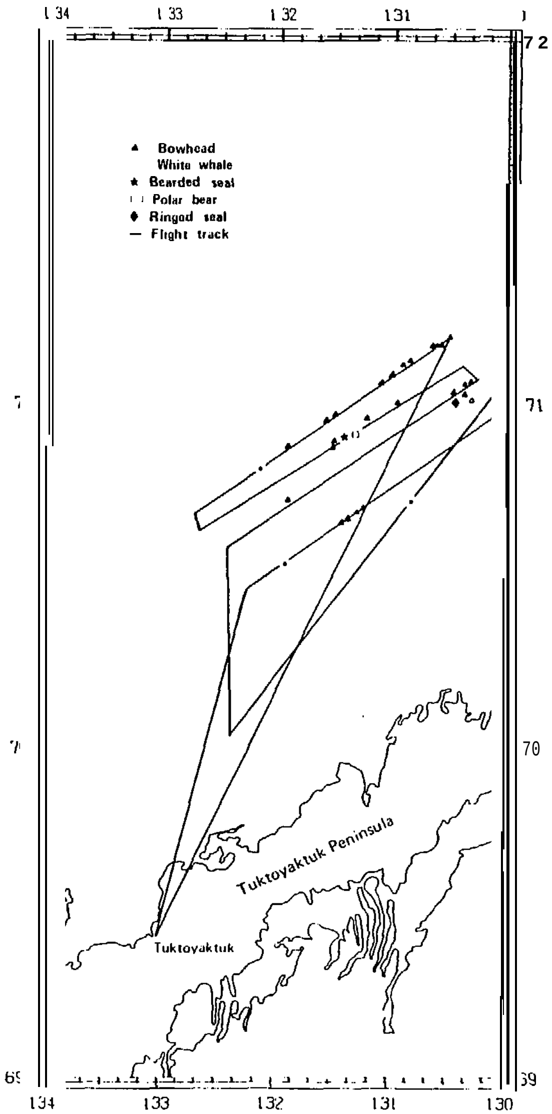

Figure 31. Aerial survey flown on 12 September to define bowhead distribu and to relocate tagged whales. There were 25 sightings of 37 bowheads, 3 sightings of 17 belugas, 2 sightings of 51 ringed seals, and one bearded seal and one polar bear sighted on this

sightings of 20 bowheads). Flights between 4 and 12 September, however, sighted large concentrations of whales 30 to 50 miles off the Tuktoyaktuk Peninsula. On 12 September, 25 sightings of 37 whales were made from an aircraft chartered to relocate tagged bowheads (Fig. 31). Despite extensive monitoring from Grumman N780, the LGL chartered aircraft, and a chartered Skymaster, no *transmissions were* received from tagged whales in the eastern Beaufort Sea after 21 August and no vessel" was available for further tagging after 24 August.

The essential tagging gear was shipped west aboard Grumman N780 on 13 September when the opportunity arose to attempt tagging in the central Beau fort Sea in the vicinity of Beaufort Lagoon. An Alaska Department of Fish and Game team had been able to approach a few bowhead whales in a 21 f t Boston whaler there during the second week in September, but by the time the tagging effort began on 14 September, severe ice conditions had set in and only a few unsuccessful attempts to locate whales were possible. Ice conditions such as those pictured in Figure 32 made it difficult to locate and approach bowheads, even when assisted by aircraft with air-to- ground communication system. Heavy ice after 20 September ended attempts to place more radio tags on bowhead whales during the 1980 season.

From 16 September through 13 October, however, flights were made in con j unction with the BLM bowhead survey team to relocate the two tagged whales as they passed the OCS lease-sale areaa during their fall migration. On one occasion during this time, a brief radio transmission was received but the presence of a tagged howhead whale was unconfirmed by either further transmissions or visual relocation (Fig. 1).

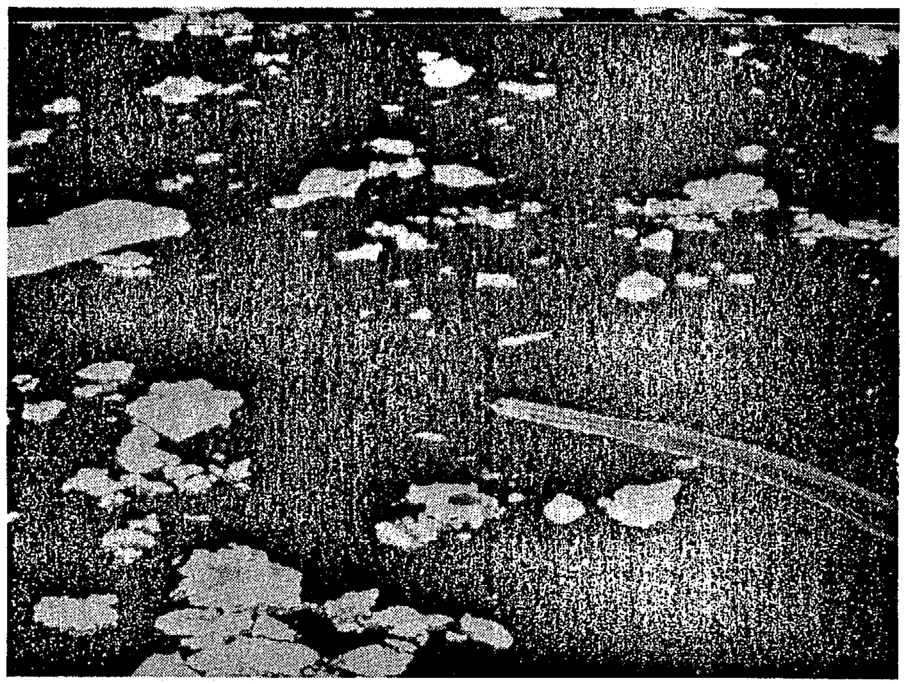

Figure 32
In September tagging efforts continued near Beaufort Lagoon, Alaska. Ice con. ditions shown here were unfavorable for locating and tagging whales in a small boat.

Discussion

As in any first year research in a remote area, logistical problems required an inordinate amount of time and effort and in some cases made it impossible to realize research goals. For example it was not possible to test the umbrella stake attachment or to photo- and videodocument the tagging effort because the scientific party aboard Ungaluk, with two distinct and immiscible research methods, was too small to accomplish these tasks. The lack of a truly reliable and seaworthy vessel capable of reaching whale concentrations quickly and staying at sea for an extended time was, and remains, the predominant problem in working on bowhead whales in the Beaufort Sea. The ideal vessel should be large enough to: 1) weather the most severe storms encountered during the summer and fall; 2) carry a crew capable of safe vessel operation around the clock for at least 2 weeks; and 3) accommodate a scientific party of sufficient size to carry out all facets of the research without undue stress (24 hour watches, tagging, photodocumentation, oversight). Because vessels are extremely expansive in the Arctic ($3,000/day minimum), a smaller, high speed vessel which could house a ship's crew of at least three and a scientific party of at least four might serve as an alternative. Such a vessel could reach whale concentrations quickly during breaks in the weather and run from foul weather as it approached.

The results of this study and some previous studies (for example, Norris et al. 1976) suggested that aircraft may be ineffective for relocating radio tagged cetaceans except in very special circumstances such as populations with highly defined migratory pathways or confined home range. The problem arises from the interpretation of negative data (i. e., does "no signal" mean the animal was not in the area covered by the aircraft, the transmitter had fallen off, the animal did not surface while the aircraft was within range, or the antenna angle precluded signal reception?) and the low probability of encountering a given cetacean in the relatively small area possible to search by an aircraft. The latter problem is compounded when the relocation effort is combined with aerial surveys since transmission reception is cut by 2/3 to 3/4 at the lower altitudes necessary for visual sightings. Distance trials using a test transmitter showed that the survey aircraft flying at 1,000 ft. over shout a 40 mile swath (20 miles on each side) and received signals over about a 140 mile swath flying at 8,000 ft. Thus, a signal could be detected from a given point on transect (e. q., a surfacing whale) for 1 hour and 10 minutes at 120 knots from 8,000 ft, while at 1,000 ft the aircraft would pass out of contact with that point in 20 minutes. Although far larger than surface vessel coverage capability, the relocation area covered by aircraft at reasonable cost, even at high altitudes, is quite small compared to the area of habitat available to highly mobile or noncoastal migrating cetaceans.

Some of the problems of aircraft location are solved if remote stations can he used to collect activity pattern, movement, and migration data from radio tagged individuals. Remote stations, however, are appropriate only for certain coastal species where a significant portion of a migratory population passes within range of the receiving antenna or where tagged individuals *remain* within range of the receiver for a prolonged period. Since this research sought to gather data on the coastal movements of bowhead whales, a contract was awarded for a prototype self-contained, portable, automated data collection unit

which could scan a selected number of frequencies at variable scan rate and reliably record time, frequency, and pulse interval for any received pulses over a two-week period. Also, since the amount of data collected during a shipboard or aircraft radio tracking study can be prodigious, the automated data collection unit, which will code and store information on computercompatible magnetic tape as well as hard COPY (ticker tape), should greatly facilitate data reduction. Unfortunately, due to a supplier delivery failure, the prototype unit was not available for testing during the 1980 field season.

The greatest difficulty in tracking whales using VHF radio tracking systems has been the lack of an AOF capable of giving an instantaneous directional readout of short pulse VHF signals without tremendous gain loss and thus greatly diminished tracking distance. Before truly successful Operational shipboard and aircraft VHF radio tracking can proceed, a VHF-ADF must be available which is comparable to that developed by Martin et al .(1971) for lower frequencies (HF).

As Mate (1980) pointed out, identifying individual transmitters with unique frequencies adds to the problem of aerial reacquisition since an animal on the surface might be missed during a receiver frequency scan even while within reception range. In order to alleviate this problem in this study, 15 transmitters were placed on the same frequency and individually identified by a unique interpulse interval as measured by a pulse analyzer (Telonics, Inc.). This system ensured no loss of reception due to a frequency scanning but had three major drawbacks: 1) three clear, strong pulses must he received to determine identity, and these pulses may not be received due to poor antenna orientation or short surface time; 2) the interpulse interval may vary over time in the field, although laboratory tests demonstrated stability to within 10 milliseconds; and 3) confusion can easily develop while tracking a tagged whale if another tagged whale is nearby or a transmitter is accidentally actuated as was the case on 21 August, 1980. If frequency scanning is to be used in the future, a locking scanner would clearly facilitate tracking. The modified scanner would hold onto an incoming signal so that the tracker knows which frequency to monitor on the following whale surfacing.

One of the goals of this research was to determine the response of bowhead whales to tagging. From previous experience with spaghetti tagging whales and capturing and handling a variety of large and small cetaceans, no adverse reaction to tagging was anticipated. Additionally, Mate (1979, 1980) observed very little reaction to the placement of umbrella stakes or barnacle tags on gray whales and even noted continued "friendly" or curious behavior after tagging. In reviewing thirteen tagging attempts with the WHOI/OAR whale tag on three spscies of whale, Watkins (1981) describes short term whale reaction to vessel maneuvering but almost no reaction to tagging per se. Others who have *used* the WHOI/OAR tag had reported some short-term behavioral disturbance and suggest that tagged animals are perhaps "more wary than usual of approaching heats" (Marine Mammal Division 1977; J.H. Johnson, National Marine Mammal Laboratory, NMFS Northwest and Alaska Fisheries Center, Seattle, WA *98115*, pers. commun.). The reactions observed in the bowhead tagging study did not differ from those previous observations. When approached by motorized vessel, bowheads generally showed some sign of avoidance.

However, when approached quietly, by sail or by oar, only the slightest reaction to tagging was noted.

The reasons for loss of signals from the two tagged whales remain largely unknown. Certainly the antenna cable connector shorts were partially responsible for the signal loss aboard Ungaluk. However, it is useful to speculate on two other possibilities: 1) the signal may have been lost due to low level inversions over the cold water (Watkins discontinued using VHF frequencies for radio tracking for this reason), and 2) although it seems very unlikely because of complete deployment, the transmitters may have been dislodged immediately by the whales. Further tests involving simultaneous tagging with HF and VHF frequency transmitters should determine the relative effectiveness and efficiency of each frequency as well as test for effectiveness of attachment and the effect of possible inversions upon signal reception.

In conclusion, the bowhead whale tagging prngram experienced mixed success. One of the major goals of the research, the determination of the feasibility of opsn ocean tagging of bowhead whales without harm to whales or taggers was completely realized and successfully accomplished add the logistical fabric for future work in the Beaufort Sea was established. In addition, this research suggests that 1) the use of aircraft for primary relocation of wide ranging, tagged whales is generally inappropriate, 2) a VHF-ADF for shipboard and aircraft tracking must be developed, and 3) further bowhead tracking requires a suitable vessel with crew and scientific party of sufficient size and dedication to insure success. Both barnacle and umbrella stake tags deployed and held well in laboratory tests on bowhead blubber, and barnacle tags deployed perfectly in the field trials. Therefore, if a suitable vessel could be acquired, there is great likelihood that a very successful tagging and tracking program could be achieved with bowhead whales.

SATELLITE-LINKED TRANSMITTER DEVELOPMENT

Because of the high cost and often overwhelming logistical considerations involved in radio tracking cetaceans by ship and aircraft, in the open ocean, responsible agencies and scientists have shown great interest during the past decade in the development of satellite-linked tracking and data collection. In order to attach satellite Transmitters to whales utilizing existent techniques (i. e., WHOI/OAR tag, barnacle tag, umbrella stake tag), currently available transmitters need an exponential reduction in power requirements because batteries comprise the major portion of their mass. A contract was awarded for the development of a processor-controller which would maintain constant frequency sl-ability, format and sequence message outputs, and process incoming environmental and physiological parameters at very low energy cost. However, the CMOS chip which was being commercially developed and therefore available at low cost for use in the processor-controller failed to meet production specifications and the transmitter development program was discontinued.

One of the most important considerations prior to undertaking a satellite tracking program was to calculate the probability of locating a whale given the orbiting characteristics of the satellite, the data necessary to solve the location algorithms, and the surfacing characteristics of the whale species being studied. While data is readily available concerning the satellite and problem solutions,

dive-surface profiles are available for only a few species, and even these profiles do not cover the wide range of activity patterns exhibited during the life cycle of the species. In actuality, a large enough sample size to ensure accurate profiles can only be obtained by radio tracking experiments.

There are two approaches that can be used to determine the probability of locating a whale by satellite. First, if information is available on the time interval between successive surfacings and if this variable can be fit to some known distribution (for example, the *normal* distribution), it is possible to simulate a dive pattern by selecting numbers at random from the appropriate distribution. The series of times between successive surfacings can then bs summed until they exceed the maximum amount of time the satellite is in view of the Transmitter, the “window”. It is assumed in this model that the duration of a dive-surface cycle is unaffected by the length of previous cycles.

Bowhead whale dive-surface data gathered by Koski and Davis (1980) and Davis and Koski (1979) from the eastern Canadian Arctic, by Wuersig et al. (1981) and ourselves from the Beaufort Sea, and by Carroll and Smithhisler (1980) from the Chukchi Sea indicated that these whales exhibit a wide variety of activity patterns. Mean dive times range from 3.7 min to ‘3.6 min with large variance, and *mean* surface times range from 1.09 min to 1.69 min again with a large *variance.*

Wuersig's dive profile indicated that there were two distinct dive patterns: a short cycle which lasted an average of 105 sec (s. d. 39 see) and a long cycle which lasted 435 sec (s. d. 56 see). It was assumed that:

1) these two patterns were equally likely and that dive cycles were independent of each other, 2) the satellite window would start in the middle of the first dive cycle, and 3) the satellite window was 780 sec (13 rein) long as is the case in the Argos system. Nine dive patterns of at least *780 sec in* duration were simulated by selecting at random either the long or short dive psttern and then selecting at random from that distribution. This was repeated until the accumulated time was greater than 780 sec. Six of these nine simulations had two surfacings within the 780 sec window, one had three surfacings, and two had four surfacings. The Argos system requires five uplinks or "hits" and thus no location solution would be possible with this profile; however it has been estimated that only three hits would be necessary for a solution with a remote user terminal (John Bryan, Old Dominion Systems, Gaithersburg, Maryland 20760. November 6, 1979 pers. commun.) It is clear that there are many other factors which enter into the successful location of whales by satellite and that a minimum of 1000 simulations should be run to get an accurate prediction.

A second approach is to estimate directly the probability of receiving a minimum number of hits in a specified time. Assuming that the dive times and surface times are independent and normally distributed and that the window can start when the animal is underwater or at the surface, the following equations apply:

If x and y are normal, where

x_i = length of time spent underwater

yi = length of time spent on surface

given $\mu_x = \bar{x}, \mu_y = \bar{y}, \quad \sigma_x = S_x, \sigma_y = S_y;$

then Pr (animal surfaces 5 times as required for an Argos location fix between I and J seconds, the satellite window) .

$$Pr\left(I < \sum_{i=1}^{4} x_i + \sum_{i=1}^{5} Y_i < J\right) \frac{\bar{x}}{\bar{x}+\bar{y}} +$$

$$Pr\left(I < \sum_{i=1}^{4} X_i + 1/2\, X_i + \sum_{i=1}^{5} y_i < J\right) \frac{x}{\bar{x}+\bar{y}}$$

Let A equal the first probability statement and B the second. Then:

$$A = \text{Standard normal probability of } \frac{J - 4\mu_x - 5\mu}{\sqrt{4^2\sigma^2_x + 5^2\sigma^2_y}}$$

$$- \text{ St. normal prob. of } \frac{I-4\mu \quad -5\mu}{\sqrt{4^2\sigma^2_x + 5^2\sigma^2_y}}$$

$$B \text{ . St. normal } \frac{(J - 4.5\mu_x - 5\mu)}{\sqrt{4.5^2\sigma^2_x + 5^2\sigma^2_Y}} - \text{ St. normal } \frac{(I - 4.5\mu - 5\mu_y)}{\sqrt{4.5^2\sigma^2_x + 5^2\sigma^2_Y}}$$

It must be remembered that the Argos system requires that the first and last hit be separated by at least 480 sec (7 rein) and that each transmission be separated by at least 4,0 sec.

Both of these approaches are really only first order approximations. Data can be more easily incorporated in the simulation procedure and it seems more flexible. The probabi li ty procedure is confounded by the fact that it is possible to get more hits than specified into the window.

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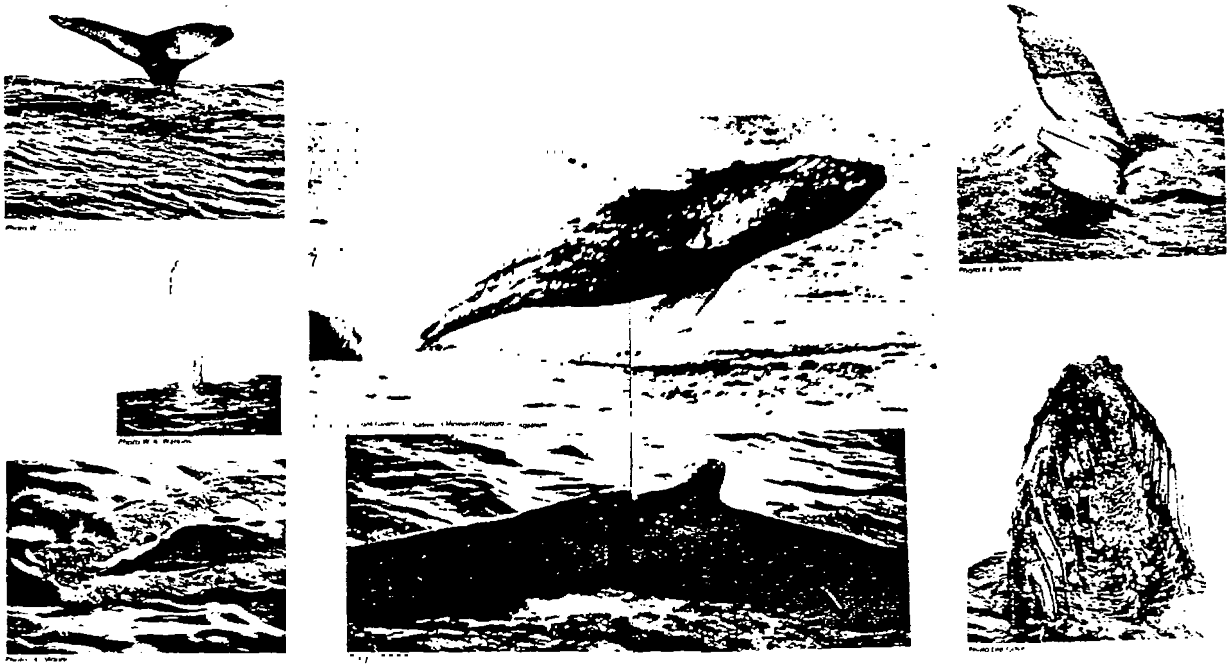
THE HUMPBACK

Megaptera Novaeangliae
Status Endangered



A Radio Tag for Big Whales

by William A. Watkins

The scientist's understanding of the behavior and movement of whale populations is limited by an inability to recognize individual animals. Usually, onlya small part of the animal is visible at sea, and then only when it is at the surface. Individuals within one pod, or even several neighboring pods may all look alike. in fact, after hours of observation, only occasionally is the whale watcher certain that the same whales are being viewed. On a recent expedition, for example, five whales were observed for several hours, with no other whales apparently in the vicinity — their respiration, dive times, behaviors, and interactions between individuals were all carefully noted — when suddenly, there were six whales. We had to start all

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Figure 1. Humpback whales are the easiest to tell apart — if there are only a few, if they spend a considerable amount of time at the surface, and if they display the underside of their flukes when diving. [Photo K. E. Moore]

over again. Had there been six whales from the beginning? They all looked so much alike that we were not sure.

Natural markings that clearly distinguish individuals in a whale population are only occasionally available. Some species have few, if any. In others, the location of their markings makes behavioral observation difficult. For example, the head growth patterns on right whales can only be seen from above, and the distinctive fluke patterns on humpbacks are visible only from below or from behind the whale (if flukes are lifted out of water).

When whales appear frequently at the surface in good weather, the observer can often detect slight variations in the animals—such as fin shape, nicks, or scars. These sometimes allow the whale watcher to distinguish between individual animals. If these variations can be photographed, certain animals can be identified from month to month or year to year, yielding important data on migration routes, among other information. Killer whale studies conducted in Puget Sound by Kenneth Balcomb and others are good examples of studies that were able to utilize such natural marks. Pigmentation differences also are potentially useful, when they can be seen. Unfortunately, the usual weather and sea conditions, as well as the whales' limited presence at the surface, make it extremely hard to recognize individuals, except under special conditions (Figure 1).

How does one label or mark a whale at sea? A variety of methods have been tried —paint, streamers, even flashing lights, and radio transmitters — but none have proved very successful, except when tested over short observation periods. We have stayed away from acoustic tags for animals that react to the noise of ships, and even to low-level pinger sounds, but use of the whale's own sounds (*see Oceanus*, Spring 1977) has been more successful, The most promising method for longer term tracking is radio; development of a useful radio whale tag appears close at hand.

Radio tags have been used to track all kinds of wildlife — from pigeons to elephants and penguins. Such a tag for whales should be a simple matter. All one has to do is find a small radio with enough power to broadcast through a wet, inefficient antenna, provide enough batteries for several months of operation, put it all into a case with insulators that will withstand a few thousand meters of water pressure, and . . . catch a whale. But radio tagging of large whales at sea has proven to be very complicated; only after many years of trying are we on the verge of developing a tag that will work.

Ideally, a radio tag should provide an identifying signal whenever the whale is at the surface. The tag should be attachable from a distance of tens of meters — most whales are not easily handled at sea and many cannot be approached for attachment by hand. Ideally, the tag should be designed so that it disturbs the whale as little as possible, while providing behavorial information over relatively long periods of time — several months, at least.

Early Radio Whale Tags

The first efforts to develop a radio whale tag at the Woods Hole Oceanographic institution began in 1961. A small transmitter was built and methods were considered on how to attach it to right whales, *Eubalaena glacialis*. Transistor circuitry had developed to a point where high-frequency oscillators could be made to fit into small pressure cases, but the big problems (then, as now) were locating battery supplies in small enough sizes, and tinding adequately efficient, rugged antennas.

During 1962, "1964, and 1965, a number of radio tags were placed on right whales. Although

Figure 2. A 1965 radio tag (1.5x 15.5centimeters). This tag was used on right whales in Cape Cod Bay. Use of the tag was limited because existing radio direction finders could not home in on the very short signals produced from the tag when a whale surfaced. (Photo K. E. Moore)

unable to track the animals, this provided us with a good introduction to radio tagging. The best tag (1965) was in a 1.5 by 15.5-centimeter cylindrical case with a wire antenna at one end and a barbed point at the other (Figure 2). The tag was attached by dropping it from a heliocopter on a weighted pole — the tag penetrated to the base of the antenna and the pole was then released and pulled back. The transmitter circuitry (140 megahertz at 1 milliwatt) operated only when the antenna was clear of the water surface.

While the attachment of the tags to the whales was successful, tracking was frustrated by damaged tags, competing radio-frequency noises, and movement of the whales away from our area. The main difficulty, however, was the lack of adequate directional receiving gear. A very rapid indication of direction was needed for the short (2 seconds or less) signals that were transmitted when the tag appeared at the surface.

During the next few years, small radio beacons were developed for use in the recovery of research instruments at sea. William E. Evans of Hubbs-Sea World Research Ceriter, San Diego, adapted these beacons so that thev could be used for tracking porpoises (Figure 3). Portable, automatic, radio direction-finding gear also was developed for Evans by Ocean Applied Research Corporation, San Diego. These systems were used in a number of very successful tracking experiments on smaller species of cetaceans. The radio attachment required that the animal be captured and the equipment tastened in place, which meant that only animals that could be caught and handled could be tagged. More recently, similar radio tracking has been done on killer whales in the Seattle area by A. W. Erickson.

Remote Attachment for Whale Tag

With the development of the automatic radio direction finders, Woods Hole researchers again began to design a radio tag that could be used at sea on tree-swimming whales, especially finbacks. Remote attachment was required, so that tracking could be done from surface vessels as well as aircraft. Our radio tag development started therefore with a frequency range (27 megahertz) and powers (200 to 300 milliwatts) that could readily be received by existing radio direction finders. With previous tests serving as a guide, it was decided to develop a system that would uses standard shotgun to shoot the tag from a ship and penetrate the blubber of a whale so that only the antenna remained outside.

During 1973, radio bands were monitored for useable frequencies, Federal Communications Commission allocations were obtained, an automatic direction finder was purchased, and floating beacons were tested for overwater transmission characteristics. By 1974, a suitable transmitter had been miniaturized that would withstand the stress of rapid accelerations. Hugh Martin and Romaine Maiefski of the Ocean Applied Research Corporation agreed to work with us on this development and undertook to work on the ballistics of the radio tag so that it could be shot from a gun. Other investigators — particularly Evans, G. Carleton Ray (see page 55), and Douglas Wartzok of The Johns Hopkins University – joined the effort and supplemented our input with ideas and funds. The complete radio whale tag was ready for testing in December 1975.

Figure 3. Radio tag fitted to the fin of a captured porpoise, Delphinus delphis. The tag provides [racking information and telemetered data on maximum depth of dive. William E. Evans, Director of Hubbs-Sea World Research Institute in San Diego, California, used these tags to provide the first hard information on feeding, offshore school movement at night, diving habits, and on the group composition of wild species. (Photo W. E. Evans)

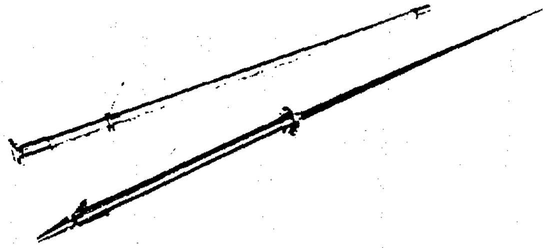

Figure 4. Latest radio whale tag (7.9x 24 centimeters). It is expected that this tag will allow the tracking of finbacks for at least 16 weeks — if the whales behave normally. The pushrod (above) fits over the antenna, projecting it during firing.

Up to this point, efforts had been concentrated on devising a tag that would be rugged enough to be shot from a gun. Now, we began to assess its reliability.

The Radio Whale Tag

The radio whale tag produced by Ocean Applied Research has a 27-megahertz, 200-milliwatt transmitter fitted into the upper end of a stainless steel tubular case, 1.9 centimeters in diameter and 24 centimeters long. The size of the case is dictated by the size of the power supply, three organic lithium batteries. The 45-centimeter whip antenna is topped by a water contact that shuts the transmitter off underwater. The lower end of the case is fitted with two hinged barbs and a penetration point. A flange at the base of the antenna limits penetration so that the tag can be imbedded in the blubber with only the antenna protruding (Figure 4).

The launching system for the tag includes a detachable, hollow pushrod that fits over the antenna and into the barrel of a 12-gauge shotgun. A line is fastened to the pushrod and allowed to pay out as the tag is fired, providing stabilizing drag tor the tag in flight and permitting retrieval of the pushrod or the entire tag if the shooter misses the whale. The push rod is secured to the tag with fastenings that release the pushrod when the tag is implanted (Figure s).

Testing the Tag

The tag was first tested on chunks of blubber and rag-filled boxes, then on whale carcasses at the whaling station at Hvalfjördur, Iceland. These tests proved that a small target could be hit consistently. The pushrod assembly provided good protection for the antenna, the transmitter circuitry worked well, and the ADF receiver gave true bearings. Despite this, a number of problems arose. Some were remedied on the spot, some required factory modification, and some were tolerated for the duration of the tests.

in Iceland, personnel at the Marine Research Institute in Reykjavik and at the shore whaling station of Hvalur H. F. at Hvalfjördur were very cooperative in aiding us with the experiments. Tags were tested on fresh whale carcasses (within 20 hours of capture); they were fired into the bodies as they floated at the base of the ramp leading to the station flensing plant. Firing positions were chosen to simulate the angles and distances expected when working at sea.

It was soon obvious that the tags were not ready to use on whales at sea, due to extremely erratic penetration. Although a few shots penetrated successfully, most turned in the blubber

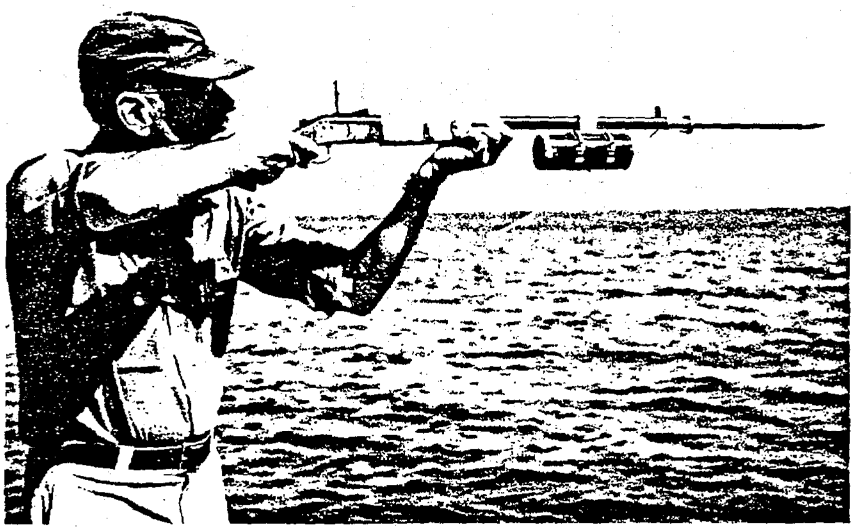

Figure 5. Radio whale tag being shot from a weighted 12-gauge shotgun, utilizing a specially loaded shell. A line attached to the pushrod pays out from the cannister, permitting retrieval of a tag if it misses. (Photo K. E. Moore)

or ricocheted off the skin. Some turned after penetration, protruding from the blubber. More work was needed to develop an improved point, a more rugged antenna, a different pushrod fastening system, a water-tight design, and a power supply that could survive the accelerations of firing. The deceleration shock against the hulk of the whale was as detrimental to the tag as that of being fired from the gun. Tests on fresh whale carcasses provided problems very different from those conducted on targets.

At about the same time as our test in Iceland, two other groups were experimenting with these radio tags on live whales. Michael F. Tillman and James H. Johnson of the National Marine Fisheries Service in Seattle tagged humpback whales, *Megaptera novaeangliae*, in August 1976, near Juneau, Alaska, succeeding in tracking one for at least six days. Tags also were tried on finback whales, *Balaenoptera physalus*, during August 1976 in the Gulf of St. Lawrence, Quebec, by Ray, Wartzok, and Edward D. Mitchell of Environment Canada at Ste. Anne de Bellevue, Quebec. They tagged and successfully tracked one whale for a little more than a day, using both aerial and boat tracking. The tag failures and ricochets that these workers experienced appeared to be similar to the problems we encountered in the Iceland tests.

A radio tag attached to a finback whale could last as long as 16 weeks. This estimate is based on our observations off Cape Cod, which indicate that over extended periods, fin backs average about one blow per minute with an average of 2 seconds at the surface. The tag now seemed potentially useful so we redesigned the faulty components.

Ballistics of the Tag

As soon as modified tags were available, thev were tested. But there were still differences in the flight and the apparent orientation of the tags as they arrived at the target. The new components had not solved this problem. The highly variable trajectory obviously was ultimately responsible tor the performance of the tag at implantation.

To discover what was happening, high-speed photography with a Fastax WF 3 movie camera at 1,200 pictures-per-second was used to study the trajectory of the tag. The first photographs revealed that the radio tag was breaking loose at the beginning of the trajectory. Upon firing, most of the fastenings between the tag and the pushrod sheared, and, as the pushrod moved out of the barrel of the gun, the tag assumed a steeper and steeper downward angle with the point of the tag dropping sharplv. Thus the tag and pushrod assumed different trajectory angles, and, in light of this, it was not surprising that the tags were erratically penetrating the targets. The photographs showed that the tags separated trom the pushrod with every shot. None of our modifications seemed to work: finally, we devised a spring-loaded connection between tag and pushrod that allowed movement sufficient to keep the fastenings from breaking, and to permit the tag and pushrod to realign in flight with only a little wobble. Perhaps a point could be found that would minimize the effects of the wobble at impact.

Duringa series of tests in 1977 in Iceland, different points were tried to see if one would perform better than others. New, modified tags were compared with those from the year betore, and the durability of components, such as antennas that had previously failed, were checked. Each whale carcass was used for three or four shots, often placed 10 to 20 centimeters apart, so that each series of shots would be as identical as possible. The high-speed photography verified the results, showing that all the modifications had been improvements.

A Point for the Tag

Our tests in Iceland were limited by the short period of time that one could work on a whale carcass, and by the number of tag components available. Since a ricochet usually resulted in losing a tag in deep water, shots were not repeated with point shapes or angles of impact that produced a ricochet. For example, the 1976 point was only used twice in these tests; one was a ricochet that lost the tag, and the second took averysharpturn in the blubber that snapped off the pushrod. In the same series, other points performed properly.

Since the beginning. otwhale hunting, some harpoon points have been found to work better than others. The harpoon head currently used by Icelandic whalers has a blunt point with tour small projections on the periphery of the tip: it is reported to have less of a ricochet factor off whale blubber. Of the tive basic shapes that we tried, the onlv point that penetrated fully and straight every time was that shown in Figure 6. It allowed the tag to

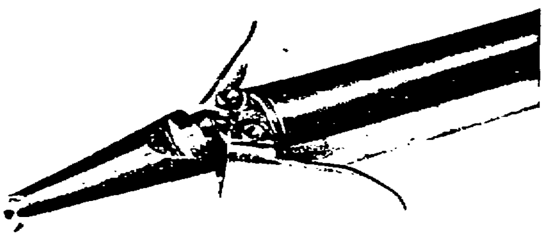

Figure 6. Point that performed best in tests on whale carcasses, penetrating even at low angles without turning in the blubber. In addition to cutting edges, it has relief channels to prevent high pressures from building up in front of the tag. (Photo K. E. Moore)

Figure 7. How long will the radio tag survive on a whale? If the answer turns out to be a considerable period of time, a finback, such as this one, will no longer be anonymous, andperhaps enough will be learned about this species to help it survive its increasing association with man. (Photo K, E. Moore)

penetrate with impact angles as low as 20degrees, it did not turn in the blubber, and there were no ricochets. It is interesting that the form of this point is somewhat like the tip of the grenade head that has evolved in the whaling industry.

Will a Whale Wear the Tag?

The tests of the radio tags on live whales have been encouraging. Tillman and Johnson conducted another experiment in July and August of 1977. Again, thev tagged humpbacks and were able to track individuals by radio for about a week. The whales did not appear to be particularly upset by the tags; they seemed to behave normally shortly after tagging.

Now we need to know how long such a tag can survive in a whale (Figure 7). Will the blubber reject our stainless steel tag or will it encapsulate and hold the tag firmly in place? A careful test series is planned this summer on both finback and humpback whales. It will be a joint experiment with all those who have been involved in the development of the radio tag. We hope the whales will be just as cooperative! We need to know if a whale will really wear the tag.

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CURSENT STATUS OF WHALE TAGGING

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INTRODUCT ION

Positive identification of individual whales allows confidence in assessments of population distributions, movements, activities, and behaviors. So often, when unequivocal ident if ications have been available, as with a radio tagged whale, the general assumptions about the animals have been demonstrated to be in error. Our own experiments with radio tags on whales have shown this. In Prince William Sound, Alaska, the finback whales (*Balaenoptera physalus*) we tagged were thought to be on their way through the area, but ins cead we found che same tagged animals almost daily in the same locations for 28 days (Watkins et *al*., 1981). Also in Prince William Sound, che humpback whales (*Megaptera novaeangliae*) had been considered to stay in small areas of the Sound, but che radio tags showed that they ranged widely, often 100 km or more a day. In Venezuela (Watkins *et al.*, 1979), Bryde's whales (*Balaenoptera edeni*) were tagged so we could work with a locally resident group of whales, but the tags confirmed that these whales only–stopped briefly on their passage through che area. And off Iceland (Watkins, 1981a; Watkins *et* al., 1981), a tagged finback whale and its companions crossed over from a population feeding on dense krill concentrations to the Greenland area to feed on scattered schools of small fish, traveling 2000 km and revising our theories on separated populations in those areas.

The potential of radio tags for understanding the biology and distribution of cetaceans has been reviewed by Evans (1974), Norris *et al*.,

(1974) , Watkins (1978), and Leatherwood and Evans (1979). The advantages of radio for tagging whales are (L) the positive unequivocal identification provided by a coded radio signal, (2) the *recognition* of the signal **in spite of darkness and weather, (3) the potential for monitoring the tag at a distance, and (4) continuous** sequence of observations, i.e. , tracking. **In addition, with radio tags there is the possibility of telemetry of** environmental and physiological information as well as 10 cation by remote receivers, including satellites.

A radio transmitter attached to a whale indicates the location of the tagged animal by broadcas ting a signal whenever its antenna is raised above the sea surface. By following a series of surface locations, the tagged whale can be tracked, and movement and speeds can be calculated. The radio signals provide a position or at *least a* direction for each surfacing of the tag, and depending on the location of the tag on the whale, surfacings can be correlated with particular behaviors such as breathing. Positioning a tag near the blowhole, for example, allows an indication of respiration and dive cycles.

Although the Discovery mark is not a radio tag, it has been implanted into thousands of whales with no apparent effect on whale behavior. All of the commercially important species have been studied through the use of the Discovery mark. This mark is a labelled tube 23 x 1.5 cm (9" x 5/8") with a penetration point. It is fired from a shot-gun into the muscle of a whale to be later found in the meat when the whale is caught. This provides two bits of information: the whale's location at the time of the shot and its location when it was caught. The properly implanted mark apparently has no effect on the behavior of the whale — no differences in behavior have been found between tagged and untagged whales. As long as

the mark did not pass through the water, there has been no reaction to the tagging (see Ruud, *1954)*. *In our experience,* it has not mattered whether **the Discovery. mark penetrated fully, or, as often happened, the cube re-**mained partially protruding; in either case there was no movement or avoidance OK sudden motion by the whale that could be related to the tagging shoe. On the other hand, if the shot, missed and the mark hit the water, the whale invariably flinched and moved away quickly. This was probably in reaction to the sharp, loud sound created by che mark hitting and moving through the *water.* Avoidance reactions are commonly noted from the chasing and maneuvering of the tagging vessel but not from the tagging itself. Because of this cons istent lack of reaction to the implantation of Discovery marks, we thought it might be possible to devise a remotely implanted attachment for a radio-tag which also would not bo ther a whale.

Radio Tags

Our first efforts to utilize a radio tag on whales began in 1961 with a series of tags that we tried on right whales, *Eubalaena glacialis* (Schevill arid Watkins, *1966).* The radio transmitters were small, MO-MHZ, l-mwatt beacons. We experimented with different power sources including sea water batteries, and we utilized a salt water switch co shut the transmitter off underwater, One of the tags also included a flashing strobe light. Attachments varied as we tried several systems from swordfish darts to wire toggles. The most successful configuration was a radio transmitter in a tube 15.5 x 1.5 cm (6" x 5/8") with a 1/4 wave wire antenna at one end and a point with wire toggles at the other. The body of the cag *was* implanted in the blubber with only the antenna external.

To implant the tag, we used a helicopter and dropped the tag on a weighted pole. The attachment ideas worked, but for various reasons we were unable to follow tagged whales. We learned much about attachments , tag frequencies and antenna transmission characteristics, but it was soon apparent that automatic direction finding (ADF) was needed for tracking of the very short signals (often 1 sec or less) from a tag on a whale. Portabl e ADF receivers, however, were not available at that time so our plans for radio tag development were set aside temporarily.

An ADF receiver for lower (HF) frequencies was developed some years later by Ocean Applied Research Corporation (San Diego) for use in the cetacean tracking work of Evans (1971, 1974) , These animals were captured and radios were attached co the fins of several smaller cetacean species, then they were released and cracked. Gray whale (*Eschrichtius robustus*) calves also were captured by Norris and Gentry (1974) , and radios were scrapped to them for short-term cracking until the harnesses were removed by timed-release mechanisms. The captive gray whale yearling (Gigi) also had a radio beacon attached before it was released (Evans, 1974) , and then it was tracked fnr several weeka. Similar radio attachments and tracks also were made on killer whales (*Orcinus orca*) by Erickson (1978) .

With the availability of AOF receivers, we went back to the development of a radio tag for big whales, and worked on a tag that could be remotely implanted at sea. We wanted a tag that could be used on any species Of large whales. The tag was co be fired from a shoulder gun at distances of 25 m nr more, and, like Our earlier tag, it was to implant with only the antenna outside the whale. Therefore, all the components had to be designed and supported to tolerate che rapid accelerations and decelerations of firing and implantation.

The development of a remotely implanted radio whale tag was a cooperative effort over quite a long time with several groups providing ideaa and resources, and the components were manufactured by Ocean Applied Research Corporation* (Watkins et *al.* , 1980). This (wHOI/OAR) tag had undergone several cycles of testing on fresh whale carcasses in Iceland (Watkins and Schevill, 1977) and field trials on live f inbacks , humpbacks , and Bryde's whales (Ray *et al.*, 1978; Marine Mammal Division, NMFS, 1976 and 1977; Watkins *et al.*, 1979; Watkins *et al.*, 1981). Analyses of the reactions of the whales to tagging (Watkins, 1981b) showed consistent response by all the whale species co maneuvering of the tagging boat but not to the implantation of the tag. The technology and experience in all phases of the development of the tagging and tracking systems has improved with succeeding experiments. In the most recent experiment a finback whale was tagged and cracked for 2000 km (1250 mi) in the open sea between Iceland and Greenland.

A more recent radio tag development by Bruce Mace uses an "umbrella stake" attachment with curved tines driven into the outer blubber layers. This attachment has proven co be Long-term and has been used with two basic radio cag packages external to the whale' s body, the "umbrella" tag and the "barnacle" tag. The umbrella tag is applied manually with a 4 m pole and consists of a small 150-MHz 10-mwatt transmitter by Telonix, ** 3.8 x 3.6 x 2.5 cm (1.5" X 1.4" x 1") mounted on a flat plate with two umbrella anchors. The barnacle tag is shoe (compound bow or gun) from about 5 m and uses one umbrella type anchor with the same 10-mwatt transmitter. Umbrella and barnac le tags have been used by Mate (1981) on gray whales in San Ignacio

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Lagoon, Baja California, Mexico, and some tagged whales were tracked over periods of months. The barnacle tags were used on bowheads in the Beaufort Sea off Tuktoyaktuk Peninsula in Canada by Hobbs and Goebel (1981) with only short-term tracking. All of these experiments indicate that the whales have no t reacted adversely to the tag implantation.

Other schemes for attaching radio beacons co whales also have been devised but generally have not generated extensive programs of testing and development. Examples are the tag developed by Erich Follmann (see Mate, 1981) and the suction cup tag by Jeff Goodyear (1981) which floats after it comes off in a few days and can he retrieved.

Characteristics of an Ideal Tag

From the experiments on radio tagging of several whale species to date and the experiences of tracking in protected waters as well as on the open sea, the ideal radio tag for whales would appear to need the following char acterist ics.

1. The tag does not af feet the whale 's behavior.
2. The tag can be attached from a distance.
3. The tag is retained over a long period.
4. The tag transmitter operates over a long period.
5. The tag has an individually identifiable signal.
6. The tag is not susceptible to damage.
7. The tag antenna is insensitive to orientation.
8. The tag signals are radiated in all directions, without interruption by local obstacles.
9. The tag signals are received at a distance.
10. The tag direction is indicated by Automatic Direction Finding receivers.
11. The tag signals are monitored automatically.
12. The tag is located easily from both the air and the surface.

The characteristics of the ideal radio tag are discussed briefly below. Examples are drawn mainly from our own experience with the WHOI/OAR tag, but it is evident that this is not a perfect whale tag. The last 3 or 4 of the listed tag characteristics are also interrelated with receiving systems. Both cag and signal receiver have to be ideal to meet these characteristics.

1. The tag does not af feet the whale's behavior. The tagging procedures and the tags should be non-interruptive co the whale. With any o f the current tag designs whales have not reacted to the tagging when approached quietly. Although whales must not ice the penetration of attachments as well as the force and weight of tags striking their body, they da not seem co react to those events, perhaps because they are over quickly and not repeated. Whales have reacted, however, to movements on their bodies, such as by a moving hand, or by a tag like our first (Schevill and Watkins, 1966) that was free to swing on an implanted anchor. After tagging, whales with the current tags have consistently acted normally and no differently from untagged companions. Other whal es have not behaved cliff erently toward tagged animals. Current tag designs, therefore, fit the ideal of not affecting the whale 's behavior.

2. The tag can be attached from a distance. To allow tagging of whales without approaching too closely (which often requires disruptive

chasing), tag attachment from a distance is needed, especially for open ocean animals. The 30-m tagging distance was considered short for the finbacks off Iceland, so we are currently trying to modify the WHO I/OAR tagging system to provide a 50-m range. Although it sometimes has been possible to maneuver quietly and approach whales very closely, in most encounters whales are ouc of reach of systems that cannot be used ata distance. Some species are more easily approached, but the ideal tag would be attachable on any large whale from a distance.

3. The tag is retained over a long period. Perhaps ideally, a tag could be removed at the end of its useful life so that its continued retention does not become a problem. Radio tags that have stopped transmitting may sometimes be able to provide information if the tags can be positively identified visually or even if they are later found in a carcass. Unfortunate y, many untagged whales are erroneously reported as having streamer tags on them so chat positive visual identification is needed. The case of each WHO I/OAR tag is numbered, recorded, and marked with a request for notification if found. This is recommended for ail whale tags. For most tracking experiments, the duration of current attachments has been demonstrated to be sufficient to provide cracking data over a few weeks (WHOI/OAR) or months (Mate /Tellonix). For longer reacquisition experiments to delineate migration patterns, for example, we probably need more realistic assessments of the action of the tags on whale tissues in order to assure long-term retention.

4. The tag operates over a long period. Tag transmitters should operate at least for the Life of che experiment, and ideally for the period of tag retention. Organic lithium batteries currently provide the most energy per size and weight. and are used in most tag designs. Special support for the batteries was needed far the WHOI/OAR tag during firing from a gun. snd hermetically sealed cells were required to avoid corrosive gas leakage, The size of the battery supply for a tag depends on a number of interrelated factors: signal power level adequate for receivers, signal repetition and pulse length (duty cycle), antenna efficiencies of both che tag and the receiver, and the desired reception distances." The WHOI/OAR tag used in Iceland had a potential operating life of about 12 months on a normally acting finback with 2 to 4 sec of signal per min. The ideal operating period of a tag would be suited to the potential monitoring period.

5. The tag has an individually identifiable signal. Each tag in an area should be identifiable, such as by different frequencies, different signal pulse rates, or different modulation characteristics. Provision is needed for simultaneous monitoring of all the tags in use in an area; otherwise, some signals may be missed while listening for others. Individual identification of tags allows concurrent work with several animals, or co trace behavioral differences, as in the Iceland finback experiment with multiple tags on one animal. The ideal tag would be uniquely identifiable.

6. The tag is not susceptible to damage. Components of che tag chat are outside the whale's body may be subject to mechanical damage by the whale rubbing against ice or ocher objects, against other whales, or depending on tag location, against its own flippers. Drag through che water

also can bend or pull on tag components. The external antenna on the WHOI/OAR tag was repeatedly modified co provide a rugged but flexible antenna to bend with the water flow but with enough stiffness to push it upward at the surf ace. To make sure that it could take the pressure of a deep dive, this tag also was tested and repeatedly cycled to a depth of 3500 m (5000 psi, Watkins and Schevill, 19?7) . The ideal tag would be rugged.

7. <u>The tag antenna is insensitive to orientation</u>. As a tagged whale moves at the surface, the orientation of the antenna relative to.. the surface of the water normally varies considerably. The usual efficiency of a tuned quarter-wavelength antenna, t heref ore, can only be realized occasionally when it stands dry and at right angles to the ground plane. Most often the tag antenna is detuned and inefficiently loads the transmitter be-cause of low angles to the water. By utilizing a partial wavelength antenna loaded electrically to be much less sensitive to ground-plane angle and by tuning for maximum out-put at 30 to 40", the WHOI/OAR tag was able to load the transmitter much more efficiency. The implanted body of this tag supported a relatively large antenna for the 27-30 MHz f requencies, so, of course, it could well support smaller antennas if the tag were used for higher frequencies. Signals from the whale tags should be radiated omni-directionally, but the position of the tag on the whale dictates the way the tag is raised out of water during a surfacing. The ideal tag would be insensitive to the variations in orientation of its antenna.

8. <u>The tag signals are radiated in all directions without interrup-tion</u>. Relatively uninterrupted, unreflected signals need to be radiated from a whale tag. This is largely frequency dependent. At VHF frequencies (above 40 co 50 MHz) signals are radiated in straight "line-of-sight" lines and are reflected by any obstacle that is a wavelength or longer in dimen-sion, with some reaction down to l/f wavelength. Thus a 150 MHz VHF signal can easily be blocked and reflected by waves or ice measuring 50 cm (20"-wavelength) or larger, while a 30-MHz HF signal would be affected by ob-jects of about 10 m (33') or larger. In addition, the lower frequencies are bent somewhat around large objects, and they may be received beyond the horizon, In sizeable seas whales usually surface only in troughs of waves, so the lower frequencies were needed to track the f inback from a ship in the stormy Denmark Strait. Higher frequencies are effectively blocked by the horizon and by all intervening wave lets, though they may be reflected well from a large object, such as nearby shore, often at a different direction. High placement of receiving antennas allow greater distances for reception of signals from tags at water level. Theoretically, the higher che tag frequency, the higher the receiving antenna needs to be since smaller obstacles become more disruptive as the wavelength gets shor-ter. The signals frnm an ideal tag would not be Interrupted.

9. <u>The tag signals are received at a distance</u>. The distance for re-ception of a signal from a whale tag depends on the characteristics of both the cag and receiving system, including the following: the tag frequency (#8 above) , the radiated power, the efficiency of the tag antenna, the posi-tion of the tag on the whale (#7 above) , the propagation characteristics of the tag frequency. Also of importance is the receiving antenna effi-ciency , relative antenna height (#8 above) , receiver sensitivity, signal-co-noise levels and bandwidths , and relative stability of the receiver and the tag frequencies. The ability of a radio receiver to discriminate

true signals from background noise depends largely on the stability of oscillators in both the tag and the receiver so that the receiving bandwidth can be narrowed to encompass only the transmitted frequencies. High stability oscillators, therefore, can provide large increases in reception distance, particularly at the lower frequencies which inherently travel further and, therefore, have more competing noise. If the direction to a tag is known, then high gain receiving antennas can be used to further increase reception distance. From a 15 m (50') antenna height, the horizon at the surface is at about 13 km (8 mi), but a line-of-sight (VHF) tag frequency can be received reliably only at about 5-7 km (3-4 mi) on a flat, calm day because of intervening swells and wavelets. At the lower (HF) frequencies, reception distances from the same antenna height are greater than 32 km (20 mi) but are limited by signal levels required by the ADF receivers and not by blocked signals (see measurements in Schevill and Watkins, 1966, of both surface and aerial reception distances). The ideal tag would be received at a distance that would allow easy tracking and relocation of a signal.

10. <u>The tag direction is indicated by ADF receivers.</u> Automatic direction finding receiver systems (ADF) are needed to provide reliable direction to a tagged whale because of the very short radio signals that are often produced only after long intervals. Highly directional receiving antennas cannot be turned effectively to find these signals, and the variable levels produced by whale tags do not permit reliable judgments of direction or proximity based only on signal level. Simultaneous comparison of two or more antennas with separate receivers allows an indication of relative direction. One of the advantages of the use of lower frequencies for surface tracking has been the availability of good ADF systems for these frequencies, providing an immediate directional reading for each signal pulse. A major disadvantage has been the high signal levels required to operate the relatively insensitive systems. The ideal tag, therefore, would be matched to the characteristics of a sensitive ADF receiving system which would provide accurate direction for the tag signals. At higher frequencies, ADF systems often function poorly because of inherent variations in signal pathways seldom a problem at lower frequencies.

11. <u>The tag signals are monitored automatically.</u> Radio signals from tagged whales provide large amounts of information on behavior if all the signals can be recorded and related to time and direction. Therefore, automatic recording of signals is highly desirable, but can only be accomplished if the signals are clearly identifiable by the equipment. In most of the early tag experiments, signals have been identifiable only by durations and repetition rates which often have been duplicated by ambient noise. Additional modulation of the signals is, therefore, desirable to assure recognition of the signal by automatic equipment. A stepped two-tone modulation is used on the WHOI/OAR "hybrid" transmitter to provide unequivocal identification of 10 transmitters on each frequency and to allow telemetry output. The ideal tag would provide an identifiable signal appropriate for automatic signal recording.

12. <u>The tag is located easily from both the air and the surface.</u> Aerial tracking allows reception of more distant signals at VHF and lower HF frequencies because of the greater antenna height, with reception distance limited by signal strength (Schevill and Watkins, 1966). The vertical tag antennas radiate in all directions horizontally but do not radiate much

off the end of the antenna, although adjacent wave faces reflect some power upward. Higher frequencies (VHF) allow efficient receiving antennas to be made smaller, but lower frequencies (HF) provide the advantage of greater low-angle radiation. For surface tracking from ships and shore, the (HF) lower frequencies may be received at considerably longer ranges (#9 above , but because of this, these frequencies are much noisier (other unwanted signals are also transmitted a long way). The ideal tag would combine the quiet backgrounds and small antenna sizes of VHF with the long range, low-angle transmission characteristics of HF. The ideal tag would be easily located by ship and shore-based antennas as well as from aircraft.

A specialized tag transmitter suitable for monitoring by satellite could provide occasional positions for tagged whales if the surfacing patterns of the whale coincided with the correct position and monitoring arrangement of a satellite. With the advent of smaller-sized satellite transmitters and satellite systems that can use shorter transmitter identification codes, the possibility of satellite tracking of tagged whales is increasing.

The discussion of the ideal radio tag for whales has shown how far from perfect current tags really are, and it has provided a comparison of the merits of different frequencies, and tagging and receiving systems. Perhaps also it has indicated that the development of an ideal whale tag is not all that far away!

For bowheads, an ideal tag would provide the same advantageous information as we have seen for other species in other areas.

1. Unequivocal identification of individuals required for precise observations — guesswork would be gone! The very same whale or groups of whales could be found again.

2. Observations in spite of weather and low visibility to provide much more complete and positive assessments without the usual interruptions.
3. Longer distance observations of tagged animals, in spite of low visibility, and with confidence that these were the same whales.
4. Continuity of data provide a track of the whale's passage with specific information on surfacing and dive intervals, speeds, and tracks.

SUMMARY

Efforts to develop radio tags for whales have continued since 1961 with considerable experimentation in the design and field testing of attachments, transmitters, and receiving systems. Two types of tags have been utilized most: the WHOI/OAR tag which is implanted remotely (at 30 m) within the blubber with only the antenna external, and the Mate/Telonics tag that is external to the skin but is attached (at 5 m) with "umbrella stake" fasteners into the blubber. From the experience with all these tags on right whales, finbacks, humpbacks, Bryde's whales, bowheads, and gray whales, 12 characteristics of an ideal tag are derived and related to bowhead work.

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HISTORICAL DEVELOPMINT OF THE SATELLITE-MONITORED WHALE TAG

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1979: Three gray whales were radio-tagged in San Ignacio Lagoon, Baja, Mexico, with low power VHF "umbrella" transmitters. The external tag was attached with two subdermal clusters of inconel wires and trailed a colored streamer. One whale was located five times along the coasts of California, Oregon and Alaska, traveling at least 6,800km in 94 days. The same tag was observed still in place 27 months after tagging (Mate et al. , 1980; Mate et al. , 1983; Mate and Harvey, 1984) . Advance?: a new housing de? ign; a new attachment strategy; preliminary assessment Of gray whale diving ability and dive patterns; determination of northbound migratory swimming speed; first measure of migratory timing for an individual whale; current distance and duration record for a radio tagged whale. Lessons: data collection was labor-intensive; limited range of VHF tag was 6 to 10 miles, surface to surface, and up to 50 miles from a plane at 5,000; good behavioral observations were made.

1980: Ten gray whales were tagged with "umbrella" tags identical to those used in 1979 and two whales were tagged with new Projectile "barnacle" tags (Mate and Harvey, 1984). Over 11,000 dives were monitored during a 50 day period and dive patterns were analyzed (Harvey and Mate, 1984) to assess the feasibility of meeting Service Argos criteria for satellite-monitored tracking (at least 5 surfacing: separated by at least 45 seconds, but within a 15 minute period) . Advance?: enormous sample size of dive durations fOr pattern analysis; evidence of whale? moving between lagoons; documentation Of individual whales moving in and out of San Ignacio Lagoon during the night; identification of a feeding area off the northern Baja Coast. Lesson: good attachment again; same transmitter limitation? as during 1979; surfacings were frequent enough to assure satellite-monitored locations.

1980-1981: Larry Hobbs, Marine Mammal Tagging Office and National Marine Mammal Laboratory, took over all tagging and development effort?. A summer bowhead whale tagging effort with VHF tags in 1980 produced no substantial data. In 1981 Hobbs left the NMML after encountering some technical obstacles in the development. of a small temperature stable Argo? transmitter (PTT) .

1982: OSU resumed development of the whale PTT in collaboration with Telonics and Or. Vin Lally at the National Center for Atmospheric Research and encouragement from NASA.

1983: The first successfully satellite-monitored whale tag (a Telonics UHF transmitter) wa? successfully applied to a humpback whale entangled In a fishing net off Newfoundland. The tag, although poorly attached with "umbrella"-like anchors, located the whale 10 time? during 6 days over a distance of 700km (Mate, et al, in press). The transmitter sent 126 messages with information about the duration of the 2 most recent dives and the transmitter temperature. Eight of the 10 locations were calculated from doppler data supplied by Service Argo? 4 weeks after the experiment; 2 were determined by a local user terminal at NASA/Goddard. The humpback whale moved off shore to an area where the Gulf Stream and Labador currents converged. This was an area where capelin, a favorite food, frequently concentrate.

Humpbacks likely use temperature gradients, like thermoclines, which are barriers for capelin, to increase their foraging efficiency. Advance?: fully remote monitoring; overlapping data between consecutive transmissions for accuracy check; temperature data; use of other satellite imagery to confirm sea surface temperature."; new pressure housing; sophisticated saltwater switch; new truncated helix (short) antenna; first functional use of a satellite-monitored radio tag on a whale; electronics worked well; overcame technical problem of small temperature-stabile oscillator by special permit from Service Argo?. Lesson: the attachments failed to deploy completely (manufacturing error); high power consumption due to oscillator and microprocessor need?; limited operational life (35 days) .

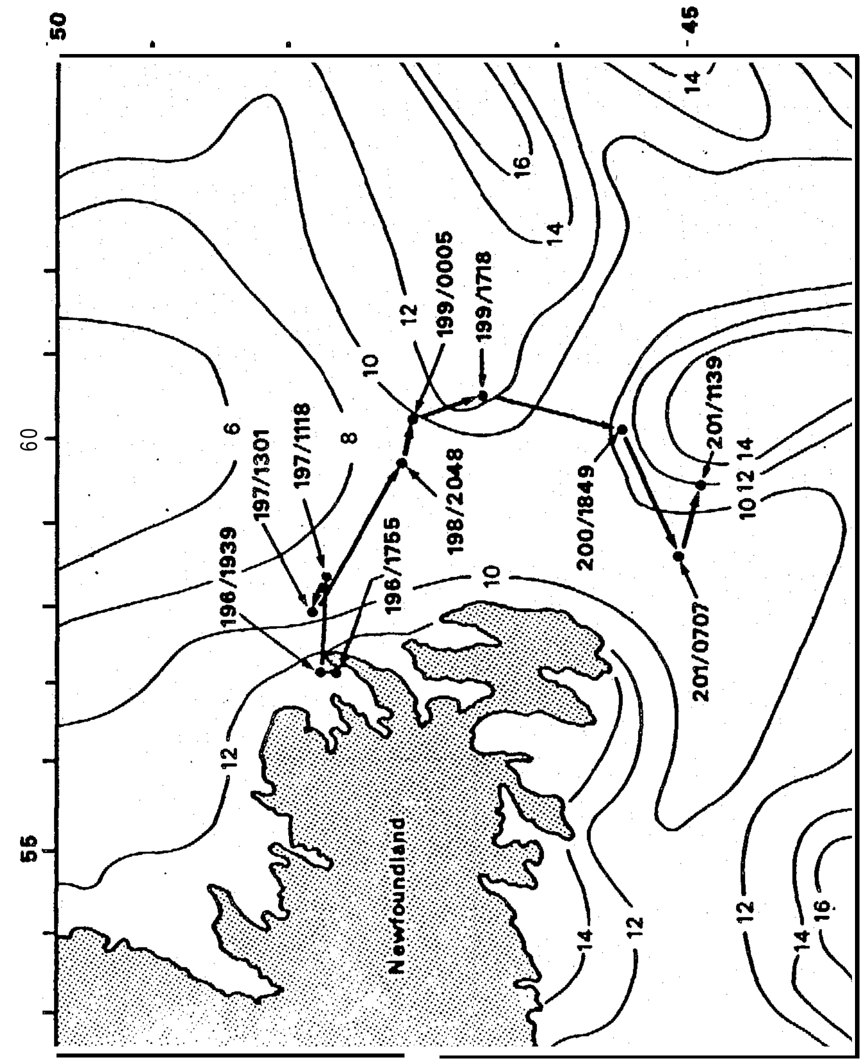
1984: A female gray whale was tagged with a satellite-monitored transmitter in San Ignacio Lagoon, Baja, Mexico, and transmitted information about dive duration, temperature and depth of the whale at 15 second intervals during the previous dive (Mate, in press). The transmitter attachment underwent severe testing immediately a? the female engaged in courtship with 2 males for three 10 minute sessions during the first 45 minutes after tagging. The tag remained attached but was only heard for a single day, during which it reported dives as deep as 55 meters and as long as 6 1/2 minutes. Advances: incorporation of a pressure transducer and software logic for sampling throughout the dive; microprocessor encoding of variable length messages and preamble? in accordance with differing amounts of data (dive duration?) . Lesson: the satellite-monitored tag was too large to be applied to whales which are in physical contact with other whales (mating or calf production), reducing the expected time of the tag's attachment.

1985: A captive manatee was released with a new and smaller transmitter in a tethered buoy and tracked successfully for 100 day?. The satellite-monitored tags in the two previous experiments used the same attachments that had been wed on the much smaller VHF tags. During a 1984/1985 sabbatical, a new suturing system was developed and a new transmitter housing was designed and constructed to accommodate the smaller electronic? package. The new attachments incorporated hollow sutures to hold antibiotics and reduce the probability of infection. Twelve sutures were used around the perimeter of the tag and were each quite strong. Advances: lower power consumption and a programmable duty cycle so transmissions coincided WIth periods of Satellite coverage.

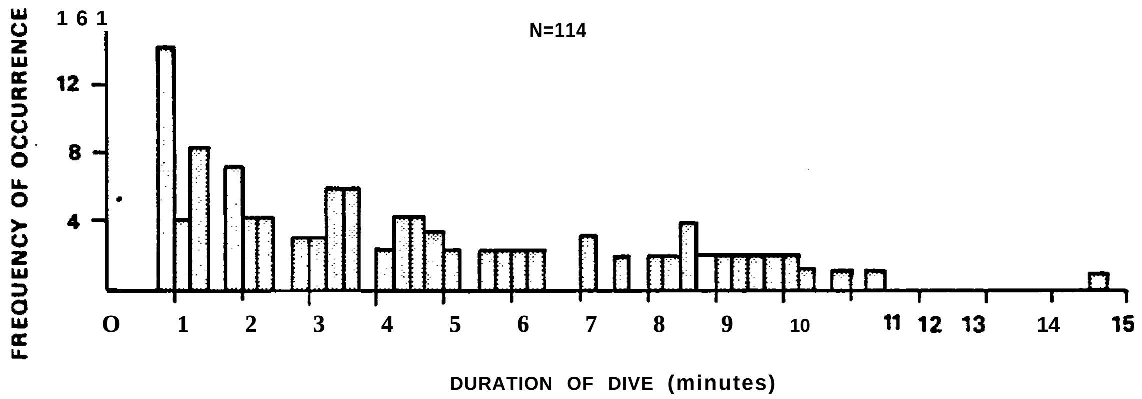
1986: A net entrapped humpback whale off Newfoundland was tagged with a Telonics satellite-monitored transmitter using the new attachment technique. The application went exceptionally well but before the whale could be completely released from the net, a rope from the net slid under the tag damaging one side of the anchoring mechanism. This resulted in a loss of the tag 22.5 hours after tagging. However, before the tag was lost, the animal moved 136km. Fifty-six dive durations were reported by transmissions from the tag and resulted in 4 locations along the whale's route. The transmitter recorded data on the duration of dives ($\bar{x}$ = 67s); water temperature; the average dive time over the last 12 hours (68s and 66s); and counted the number of dives during the last 12 hours (650). Advances: with lower power consumption and an 8 hour duty cycle, the operational life of this tag would be 8 - 11 months; more data is reported, including some in a statistically summarized form using the on-board microprocessor for computations, as well as encoding and operational duties. The incorporation of a counter to keep track of dives between transmissions allowed a more accurate analysis of diving behavior and patterns. Lesson: the new tag attachment remains inadequately tested due to the unfortunate damage received by the net during release. The tag electronics worked very well and the attachment itself went smoothly, without overt animal reaction.

During September, two bowhead whales were tagged in the Canadian Beaufort Sea with VHF projectile tags (Ljungblad, et al). Lesson: this was the first successful tagging of bowhead whales and demonstrated that the whales can be approached at close range. Goodyear (pers. comm.) was also successful in applying projectile tags during September 1986.

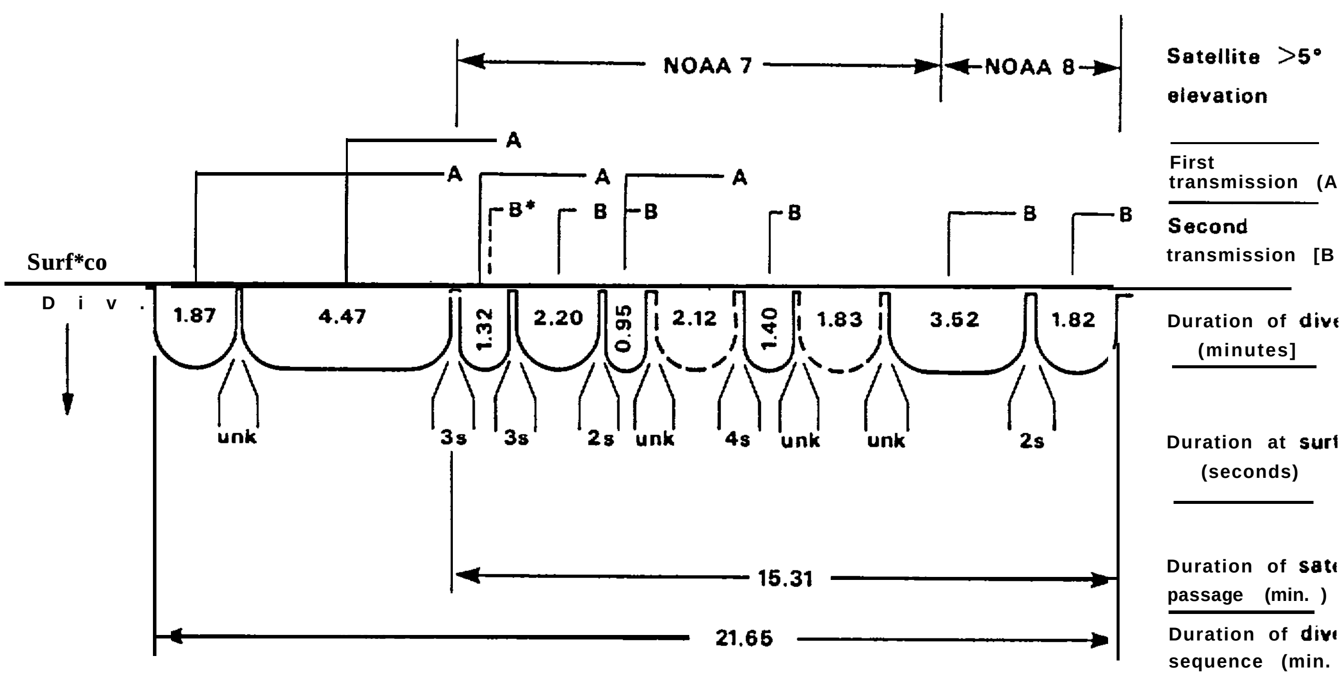
Three manatees were tagged off the west coast of Florida using a satellite-monitored transmitter (as developed for whales) in a floating housing, as before. Two of these tags were removed after 4 months: one by a shark and one by a fisherman. The third instrumented animal had its tag removed by Fish & Wildlife Service personnel after 11 months of successful operation. An average of 2 locations a day were calculated for all animals during their free ranging periods. Eleven months is the longest period of tracking for any animal by satellite (either marine or terrestial). This program has now been expanded by the U. S. Fish and Wildlife Service. Advances: the long term longevity of the electronics in a marine application has been demonstrated; transmitters have been recovered, rebatteried and put back out on additional animals.



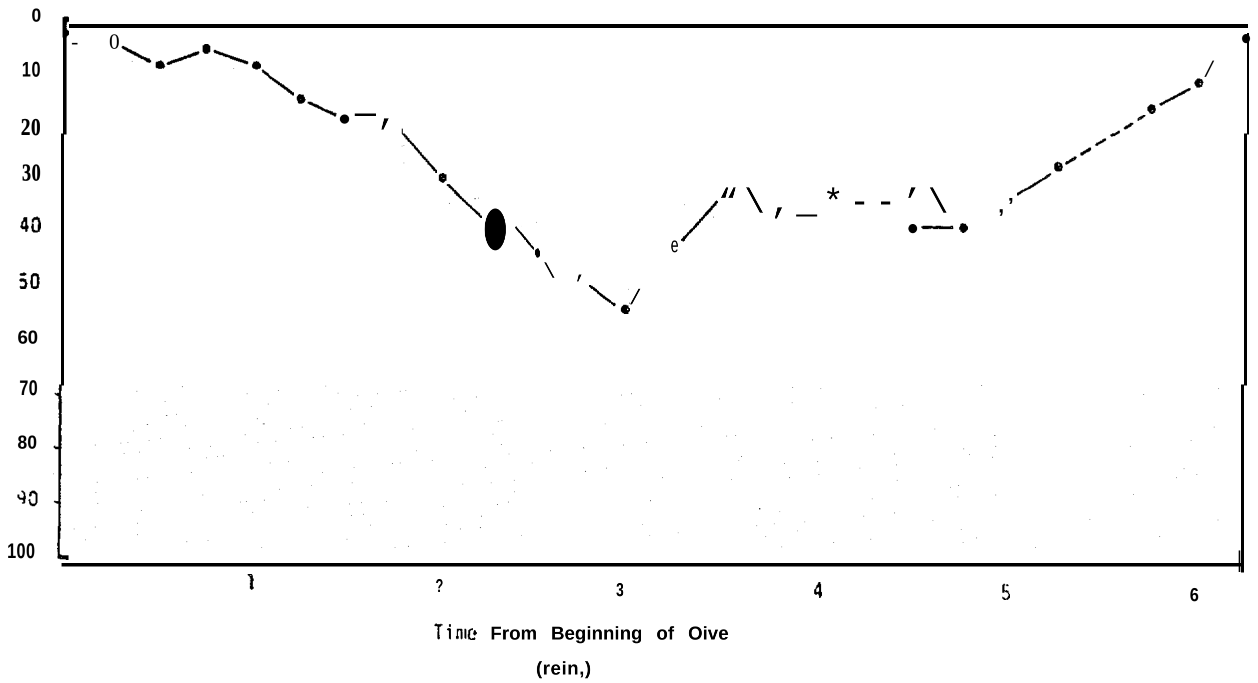
The track of a satellite-monitored humpback whale tagged off Newfoundland in July 1983. en locations were determined from 126 messages received during the 6 day period.



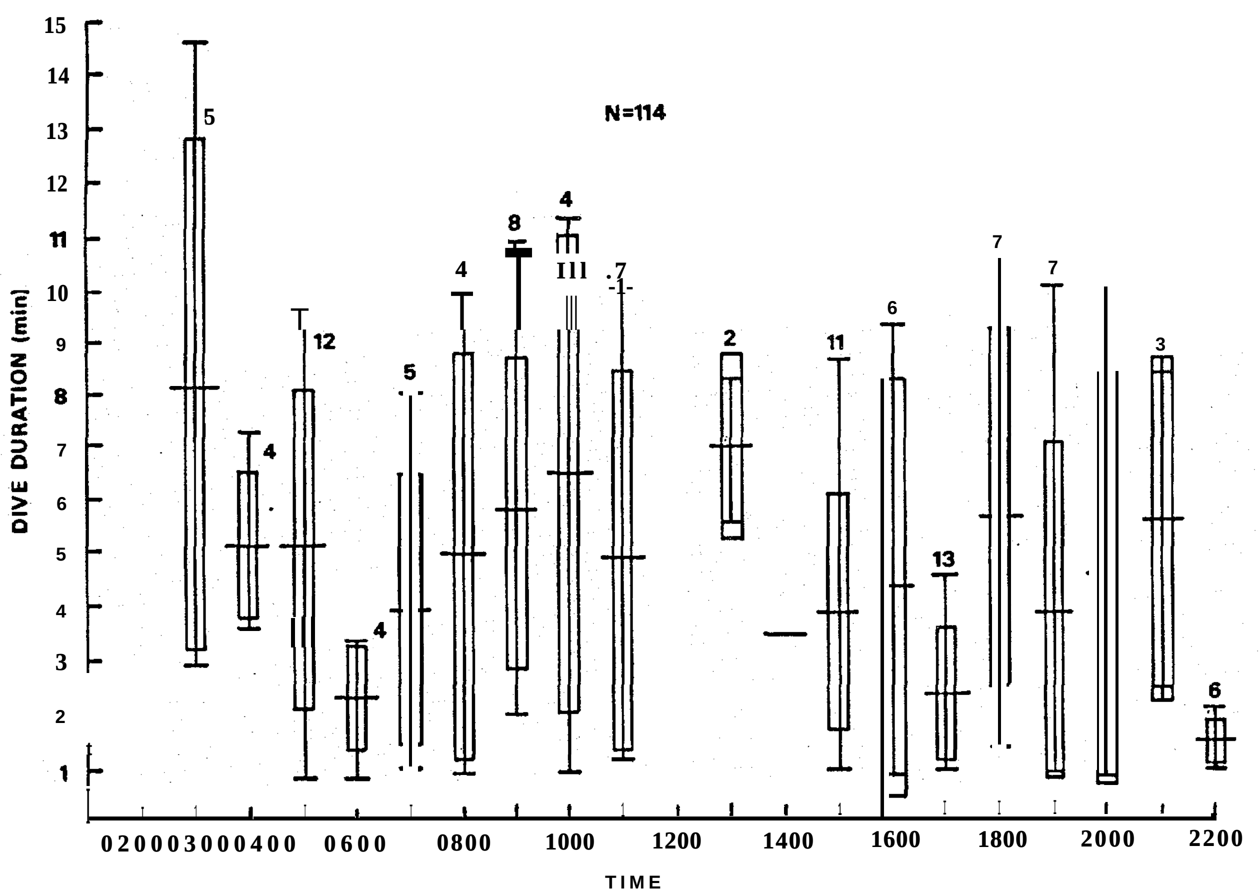
The frequency distribution of humpback whale dives monitored by satellite.



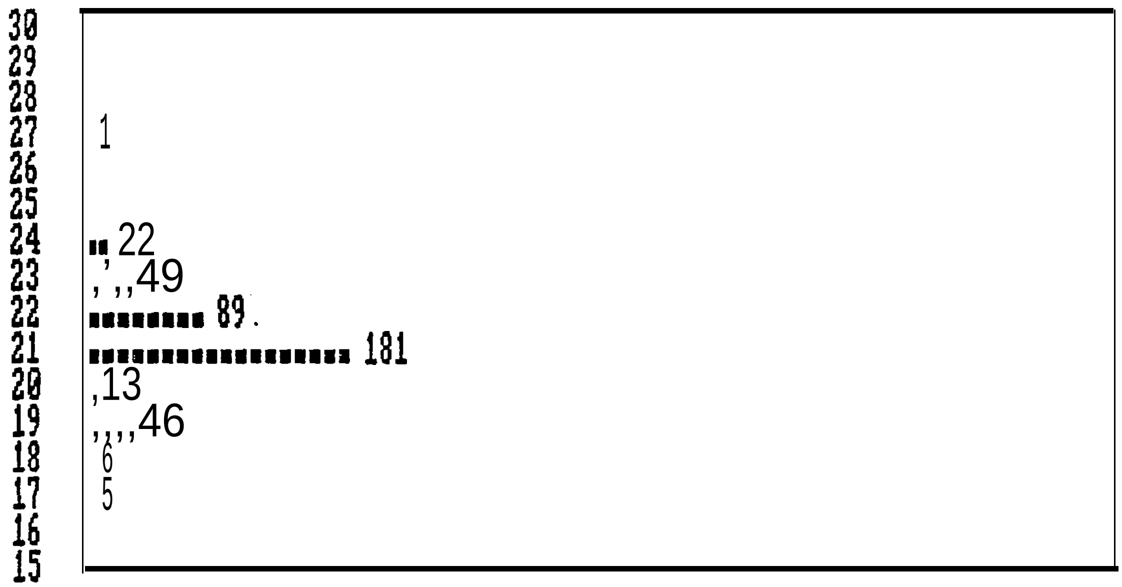
A diving sequence of a satellite-monitored humpback whale of f Newfoundland in July, 1987.



The dive profile of a gray whale off the Baja, Mexico Pacific coast. The dive is 6.25 minutes long and reached a maximum depth of 55 meters,



The duration of dives at different times throughout a 6 day period from a satellite-monitored humpback whale.



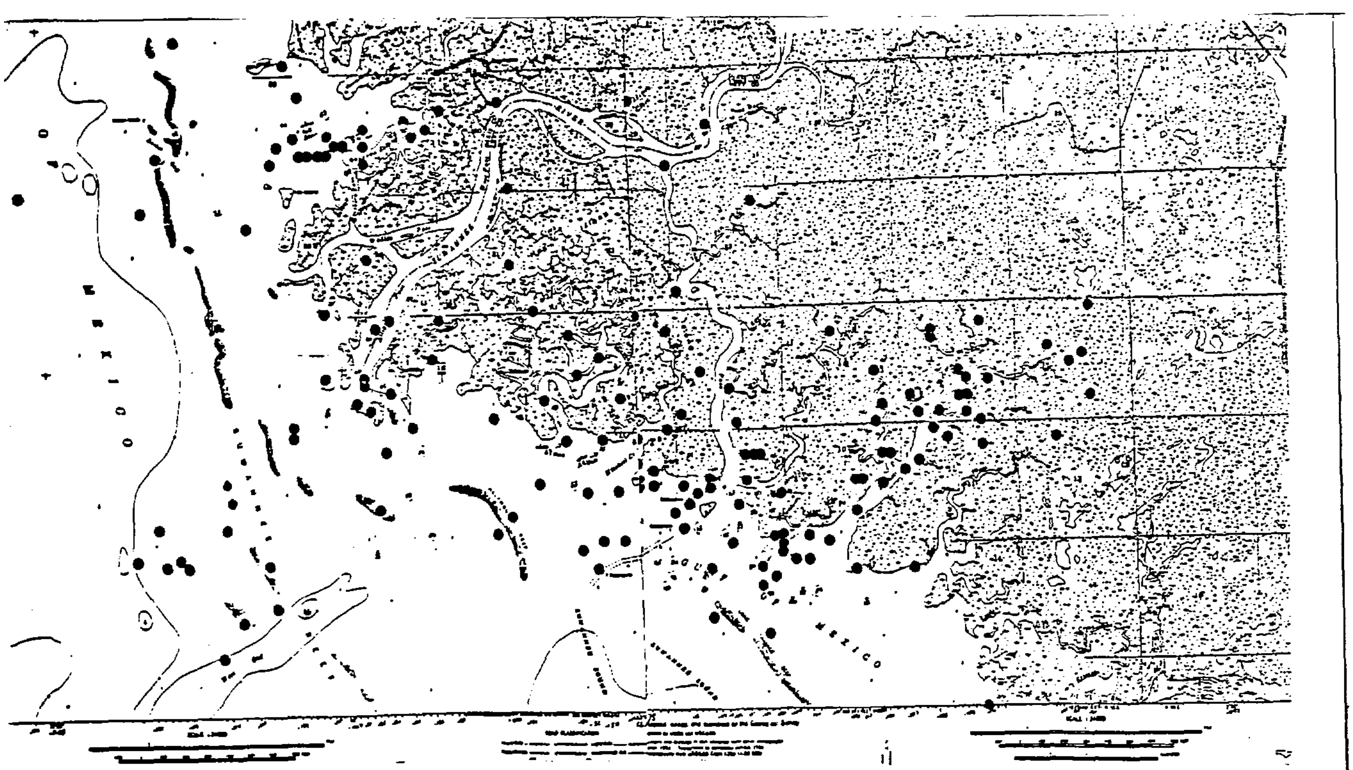
SAMPLE = 412
VARIANCE = 1.988671
6.947569E-02

COEFF. VAR. = 6.626408
STD DEV = 1.410203

MEAN = 21.28155
STD ERR =

PLOT OF TEMPERATURE

Surface water temperatures reported from a free-ranging manatee equipped with a satellite-monitored radio tag, showing a strong temperature preference for water 21° +C found only in inland waters during winter. The 70 records of colder temperatures occurred during ocean movements between river systems.



The locations of a free-ranging manatee off western Florida for 30 days, as monitored through the Argos system on Tiros satellites.

13. Gray Whale Migrations along the Oregon Coast, 1978-1981

Denise L. Herzing and *Bruce R. Mate*

Summary

To determine the temporal and spatial distribution and pod size of the California gray whale *Eschrichtius robustus* along the Oregon coast, whale movement was monitored from November through May during 1978-1981. Primary observations were made from shore, and supplemental observations were from aerial surveys. The migration occurred in three major phases: (1) southward migration (early December to mid-February) which peaked in early January at a maximum rate of 29 whales/hr; (2) northward/Phase A migration (mid-February through April) which did not include calves and peaked in mid-March at a maximum rate of 14 whales/hr; (3) northward/Phase B (cow/calf) migration (late April through May) which peaked in mid-May at a maximum rate of 6 whales/hr. Over 50% of all whales in the combined southward and northward/Phase A migrations passed by Yaquina Head between 1.6 and 32 km from shore. Pod size decreased and whales moved progressively closer to shore throughout the northward migration. The cow/calf migration was characterized by a high percentage of singles and pairs (90%) and travel within 1.6 km of shore (97%). In the 1980-1981 season, an estimated 15,462 whales migrated past Yaquina Head during the southward migration. Discrepancies in the estimated number of calves and total estimated number of whales passing south and north by Oregon may be attributable to late migrants, animals summering south of the study area, and higher mortality rates of calves during their northward migration.

24. Dive Characteristics and Movements of Radio-Tagged Gray Whales in San Ignacio Lagoon, Baja California Sur, Mexico

James T. Harvey and Bruce *R. Mate*

Summary

Ten gray whales, *Eschrichtius robustus* were radio tagged and monitored in San Ignacio Lagoon, Baja California Sur, Mexico, from February 9 to April 15, 1980. Mean duration of dive for individual whales varied from 1.0 to 2.6 min ($\bar{x}$ = 1.6 ± 0.02 min). Ninety-nine percent of the 11,080 dives recorded were less than 6 min and 49% less than 1 min in duration. The longest dive was 25.9 min. Tagged whales averaged 4.4 ± 0.06 sec at the surface per surfacing. Eight of the tagged whales averaged less than 2.9% of the time at the surface (range, 1.56- 16.3%). The tagged whales averaged 35.6 surfacings per hr. Three surfacing patterns were documented (regular-long, regular-short, and clumped) which accounted for approximately one-half of all dive sequences analyzed for two whales. Three radio-tagged whales were monitored for 4, 5, and 11 days, and moved into the ocean on 2, 2, and 7 occasions, respectively. Most oceanic movements were at night and 40% were against the tide. Seven of the tagged whales did not remain in the lagoon for more than 2 days.

25. Ocean Movements of Radio-tagged Gray Whales

Bruce R. *Mate* and James *T. Harvey*

Summary

Eighteen gray whales were radio tagged using two different subdermal attachments: a projectile "barnacle" tag and an "umbrella" tag, applied at the end of a pole. Umbrella tags were easier to position than barnacle tags, and thus had better antenna orientation. Umbrella tags are known to have remained attached for up to 27 months, and signals from radio tags have been received up to 94 days after tagging (6680 km from the tagging site). Locations of radio-tagged whales have been determined using receivers on land and aboard aircraft. The average distance traveled per day during the northward migration was 85 km/day and was greater farther to the north, estimated at 127 km/day for the last 29 days. No differences were found between maximum calculated swimming speeds of single adults and those of females with calves. Some tagged animals rewed both south and north from the tagging site (Laguna San Ignacio, Baja California Sur, Mexico) 10 adjacent calving/breeding areas. A few lingered around Laguna Ojo de Liebre and 1 whale was found apparently feeding with up to 60 other whales in an area along the northern Baja coast. Future technology may well allow collection of sensor data and location information telemetered by satellite.

Tracking manatees and evaluating their habitats by satellite

Mate, Bruce, Galen Rathbun and James Reid

On 5 February 1985 a West Indian manatee (*Trichechus manatus*) was tagged with a 401.650 MHz transmitter, which was monitored by the Argos (satellite) Data Collection System for 114 days. The radio floated in a cylinder and was tethered by two swivels and a 2m nylon-rod to a belt around the manatee's caudal peduncle. The animal was kept in captivity for two weeks after tagging to collect ground truth information, which resulted in 46 locations. Ninety-five percent of all locations were within 500 m of the holding area. After release, 36 days of free-ranging activity resulted in 91 locations of the manatee, averaging 2.53 locations/day.

Fifty days after tagging, the animal was relocated and the functioning transmitter removed to replace the batteries. The transmitter was reapplied on 15 April and during the next 64 days, 117 locations were determined (an average of 1.83 locations/day). Up to 5 locations/day were determined. The released manatee moved between known manatee habitats: the Homosassa River, the Suwannee River and the Withlacoochee River. During the last two months, the tagged manatee foraged in an area of approximately 80 square kilometers. Visual sightings confirmed that the tagged manatee associated with other manatees and is evidence that rehabilitated animals can be successfully re-introduced into the wild. The transmitter sent temperature and motion sensor data. Temperatures were significantly different between the day and night, suggesting differences in activity patterns. Activity sensors on the transmitter were most active when the animal moved long distances.

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Fin whale *(Balaenoptera physalus)* tracked by radio in the Irminger Sea

by
William A. Watkins, Karen E. Moore,
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Douglas Wartzok,
and
Giuseppe Notarbartolo di Sciara

Fin whale *(Balaenoptera physalus)* tracked by radio in the Irminger Sea

by
William A. Watkins,[1] *Karen E. Moore,*[1]
Jóhann Sigurjónsson,[2]
Douglas Wartzok,[3]
and
Giuseppe Notarbartolo di Sciara[4]

ABSTRACT

A fin whale *(Balaenoptera physalus)* was radio tagged 155 km southwest of Iceland and tracked continuously for 9½ days, 25 June to 5 July, 1980. It travelled more than 17(SJ km and passed within 110 km of Greenland. Detailed analysis of surfacing patterns, swimming speeds, association with other whales, and diel behavioural changes were made possible by the radio tag signals, which were transmitted when the whale surfaced. The whale fed on krill off Iceland and schooled fish off Greenland, The average interval between surfacings was 1.98 min including the shortened intervals in clustered blowing. The average speed over the entire track was 7.4 km/hr. There were diel changes in activity in spite of less than total darkness at night. The tagged whale's crossing of the Irminger Sea, often in close association with conspecifics, is the first direct proof of an east-west movement of a fin whale between Iceland and East-Greenland, and an additional proof of mixing of whales between the two areas

INTRODUCTION

A fin whale *(Balaenoptera physalus)* tagged with radio transmitters was tracked from near Iceland to Greenland waters from 25 June to 5 July 1980. Details of the preparation for this open-sea radio tagging experiment and a preliminary field report were given by Watkins (1981a, 1981c).

During the past *20* years the distributing and movements of the fin whale population harvested west of Iceland has been studied by Discovery-marking (Jónsson 1965; Jonsgård and Christensen 1968; Rörvik et al. 1976; Brown 1979; Sigurjónsson 1983). Fin whales marked off western Iceland have been recovered in the same area where they were marked. Three fin whales marked off East-Greenland in 1968 (Rörvik et al. 1976; Brown 1979) and one in 1973 (unpublished data), all recovered on the whaling grounds of Iceland, indicate some mixing of fin whales across the Irminger Sea. A recent analysis (Sigurjónsson and Gunnlaugsson, in press) has shown that there dries not appear to be a free mixing of whales between the two areas, although the fin whale population in the Irminger Sea has been considered a single stock for management purposes (IWC 1977). The general understanding, supported by short-term mark recoveries (Rörvik et al. 1976; Sigurjónsson 1983) was, however, that fin whales harvested west of

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Iceland remain within the whaling area (approximately fr2° 30' to 66°N, 24° to 30°W) for some weeks at least. Consequently, the logistics of our radio tracking experiment were planned 10 follow tagged whales in the whaling area and to gather information about movements, distribution, and behaviour of the "Icelandic" fin wholes.

The whale wits tagged and tracked with the W HOI/OA R (Woods Hole Oceanograpbic Institution, Woods Hole, Massachusetts, and Ocean Applied Research Corporation. San Diego, California) radio tag designed for remote implantation at sea on large unrestrained whales (Watkins et al. 1980). previous tests of the tag during development had been conducted on fin whales in relatively protected waters in the Gulf of St. Lawrence (Ray et al. 1978) and in Alaska (NMFS 1977; Watkins et al. 1981). These and previous tests on humpback whales *(Megaptera novaeangliae)* and Bryde's whales *(Balaenoptera edeni)* demonstrated that the radio tags were well tolerated, and that the behaviour of tagged whales appeared to he normal (Watkins 1981 b).

METHODS

Four fin whales were tagged to test the *radio* tagging system in the open ocean, and the last of these was retagged and tracked continuously as long as logistics permitted. The 46-m Icelandic whaling vessel, *Hvalur* 6, was used to approach the whales for tagging, and a 40.5-m Icelandic capelin fishing vessel, *Ljósfari*, was used for (racking. The Icelandic whaling company Hvalur, Ltd., and the Marine Research Institute, Reykjavík, participated directly in the tagging and tracking activities.

The radio tags were 29 cm long and 1.9 cm in diameter (Watkins et al. 1980) with a point developed for blubber penetration (Watkins 1979). Folding toggles and "hula skirt" projections (Watkins ct al. 1979), were used to insure retention after penetration. The tags were disinfected with benzalkonium (zephiran) chloride and then fired from shoulder guns. The tags were implanted at an angle with only the flexible antenna (45 cm long and 0.9 cm in diameter at the base) protruding from the whale's skin. The tags on the double-tagged whale had separate radio frequencies (27.420 and 27.520 MHz). Signals were transmitted only when the tag antennas were out of water (two 50 mscc pulses per sec at 200 mwatts). Each tag also curried an external coloured plastic streamer (5x6O cm) to facilitate visual recognition (NMFS 1977).

Iceland time was used during the tracking and the analyses. This was approximately two hours ahead of local sun time.

Tracking of the two radio signals was achieved by means of separate automatic direction-finding receivers (OAR) with antenna mounted on the forward mast of the *Ljósfari.* Direction for each signal was indicated accurately, but because of the whale's variable surfacing behaviour and orientation of the tag antennas, the signal levels could not reliably indicate distance. Signal occurrence was recorded on a timed strip chart. To avoid chasing or disturbing the whale, the tracking vessel travelled on a parallel course rather than following behind, usually keeping the whale at a 45" angle on either side of the bow, at a distance of 1 to 5 km. Close approaches were attempted daily at different times for observation and photography of behaviour and the implant sites. Figure 1 indicates the track of the vessel from Loran C positions (usually taken hourly). Although this track generally minimized the actual swimming distance and smoothed small-scale excursions by the whale, sometimes the ship also may have outrun the whale. Overall the Loran track closely matched the whale's track.

Travel speeds were calculated from the Loran positions, and represent averages. Distances were measured in nautical miles

from the charted positions. The short-term deviations in the track and consequent variations in speed were averaged over longer periods. During a portion of the track, the ship's speed was limited to about 8 knots by engine problems, so it was sometimes difficult to keep up with the whale. The whale's track, therefore, was less accurately represented during periods of mpid movements, such as during the feeding and social activity of the last parts of *the* track, but it was probably well represented during the relatively constant-speed travel of the passage across the Irminger Sea.

Results are given in three ways: Table 1 lists daily positions, activities, approximate distances, and average speeds of the track; Figure 1 plots the ship's Loran C positions, beginning at the implantation of the first tag, at 2200 hrs on 25 June 1980, and ending at 0610 hrs on 5 July; and the narrative gives behavioral details, particularly of the beginning period of the track to show that the tag, did not appear to affect the animal's activities. Times in the narrative are approximate.

Assessments of the whales' activities were based on our combined experience observing finbacks (Schevill et al. 1964; Ray et al. 1978; Watkins and Schevill 1979; Watkins 1981b, 1981c; Watkins et al. 1981). "Clustered" and "single" blowing were distinctive respiratory behaviors, demonstrated by the radio signal patterns. "Social" behaviour included periods when fin whales in close association surfaced slowly together, repeatedly, with no apparent feeding or other activity. Social activity sometimes included rolling onto the side and considerable non-feeding, near-surface commotion.

RESULTS

The 21-m fin whale, nick-named Kristján ("K'), was radio tagged at 2200 hrs on 25 June 1980, at 63° 19'N, 25° 49'W, about 83 naut. miles (155 km) southwest of Iceland (Fig. 1). The signals from K were tracked

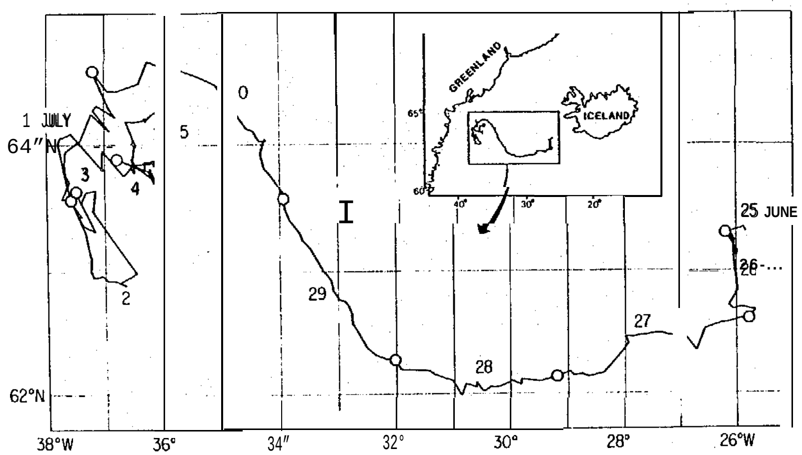

Figure 1. The approximate track of the radio tagged fin whale from 25 June to 5 July 1980 plotted from hourly Loran-C positions of the tracking vessel. The circles indicate midnight positions.

continuously for 9 days and 10 hours, ending at 0800 hrs on 5 July at 64°07'N, 36°09'W (the position where the ship stopped for repairs at 0610 hrs), about 86 naut. miles (160 km) southeast of Angmagssalik, Greenland. The closest approach to Greenland was within 59 naut. miles (110 km) at midnight on 30 June. The daily progress of the whale's track across the Irminger Sea is given in Table 1, with distances and speeds calculated on the basis of surfacing (dive time) data from the radio signals. The smoothed ship track was approximately 900 naut. miles (1700 km) long; the whale's track was considerably longer.

Approaches for inspection of the tags and observations of the whale's behaviour were accomplished without difficulty when K was accompanied by one or more other fin whales. However, K was difficult to approach when alone and not occupied with feeding near the surface, or during long-submergence routines. There were 22 close approaches made at irregular intervals, one to four each day except for 30 June, a stormy day. Except for one feeding blue whale (*Balaenoptera musculus*) on 25 June, all whales seen in close proximity to K were finbacks. Often it was difficult to be sure of the number of whales that should be considered as companions because other more distant whales may also have been associated with K. Of 37 close associations (within 200 meters), K was seen twice with six or more companions, once with four companions, four times with three, eight times with two, 15 times with one, and K appeared to be alone on seven occasions (no other whales observed within 2 km). These group associations generally remained stable over observation periods of 30 min or longer and did not include the 5 or 6 individual whales seen joining K for only short periods of one or two blow series. When the whales could be distinguished by size, fin shape, or markings, we recognized that K's companions changed at least daily.

NARRATIVE

25 June. The first tag was implanted on K at the base of the fin on the left side (Fig. 2). Another tag fired simultaneously struck the water and startled the whales (tags implanted above the water line produced no obvious reaction; see Watkins 1981b). When approached for tagging, there were four 18- to 21-m finbacks in the area feeding on dense patches of krill, probably *Meganyctiphanes norvegica,* visible near the surface. With the maneuvering of the tagging vessel, the whales stopped feeding and separated temporarily, but remained in the area with the two vessels. Within 35 minutes after tagging, K was again feeding on krill, accompanied by three fin whales and one blue whale. The radio signals from the tag (at the base of the fin) were received only when the whale raised its back well out of water. Calm weather and the high-latitude long daylight allowed signals to be matched with observed behaviour.

26 June. Throughout the night K accompanied a slightly smaller fin whale, moving about 8.5 naut. miles (16 km) as they fed periodically. They were joined intermittently by other fin whales. No behavioural differences were observed between K and its non-tagged companions. The whales remained near the surface, with submergences of less than three minutes followed by one or two blows. The tag antenna was lifted partially out of water and transmitted during many of these surfacings. Then, at approximately 0430 hrs, the whale's dive periods lengthened, and blowing occurred in clusters of 5 to 7. The fin tag was now transmitting only during a "round-out" at the end of a blow series, as the whale began a new dive, as described by Watkins (1981c, Fig. 4, p. 93). The reduction in tag signals confirmed the need for a tag placed higher on the whale's back nearer the blowhole, so that the tag would transmit synchronously with respiration.

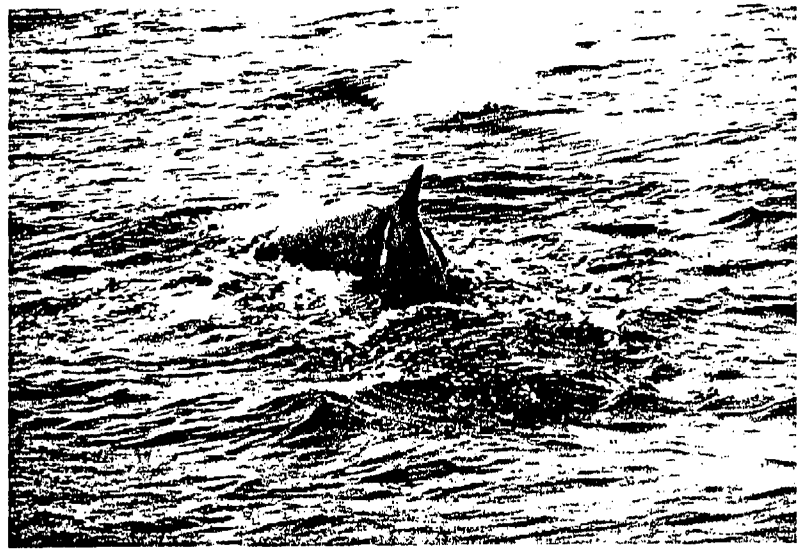

Figure 2. The "fin" radio tag implanted at 2200 hrs on 25 June on a finback whale. A coloured plastic streamer was used to make the tag more visible. This tag proved to be too far aft on the whale for antenna exposure except when the whale arched its back high out of water as in this photo (by Karen Moore).

The numbers of whales varied as they moved from one concentration of krill to the next, with new whales joining the group and others leaving. By mid-day K was keeping close company with a different fin whale and the two continued together, periodically meeting other whales as they fed.

A second tag was implanted at 1245 hrs, approximately 3 m behind K's blowhole and 25 cm to the right of the midline. There was no visible reaction to the tag implantation. K and its companions avoided the maneuvering tagging ship but returned to feed nearby within minutes of tagging. The higher forward position of the tag on the back resulted in signal transmission during most respiration surfacings, while the fin tag transmitted only when the whale lifted more of its body out of water. At 1500 hrs the *Hvalur 6* moved away and the whales were monitored from the *Ljósfari.*

Three hours after the second tagging, K and its companions stopped feeding and began to swim slowly in a southerly direction. Respiration was regular, often single blows at 2 to 3 min intervals. At about 1700 hrs the whales began to dive for longer periods (7 to 9 min) followed by 5 to 7 blows clustered within 2 to 3 min. K was again feeding on near-surface krill at 2000 hrs with three other fin whales, and as they approached the ship an attempt was made to place a third tag on K. The tag missed, striking the water, and all four whales startled and moved rapidly away. They returned within minutes, however, and resumed feeding. By 2200 hrs radio signals indicated shallow dives with one or two blows every 2 to 3 min. **Signals were received from** the forward **tag at each blow** but **only** occasionally from the fin **tag**.

27 ***June.*** Between 0130 **and 1400** hrs **the** four whales swam near the surface **on a** relatively straight, westerly course, blowing once or **twice** every **1** to 3 rein, with few **signals** from the fin **tag (only** one signal between 0701 and 134 t **hrs)**. The weather deteriorated and seas increased in height to about 5 m, but the **radio** signals continued to allow **reliable** tracking.

K appeared to be alone and traveling such a straight course that we wondered if it were reacting to the **vessel.** To test **this,** the ship changed sides several times and crossed in front of the whale. There was no reaction to changes in ship's position, speed, or sharp turns (which create loud cavitation noise) **unless** the whale was within about **200** m; then K increased its submergence time to avoid the ship, sometimes diving to pass underneath. We had wanted to remain close to Iceland to test the tags and the tracking procedures conveniently near the base of operations (Watkins **198** la), and we woutd have been happy to find that K could be turned. However, throughout the morning K maintained a 5 knot speed and a westerty course.

At 1530 hrs K began longer submergence of 4 to 6 min with clustered **blows. It** was with another fin whale, and both maintained a westerly course. By 2300 hrs the whales' respiration pattern was one or two blows at intervals of 1 to 3 min as they swam near the surface.

28 ***June.*** At 0430 hrs the tag signal patterns **showed lengthening dives** with **clustered** blows. By **0900** hrs the submergence ***were*** 6 min or longer, and K was with two other (different) fin whales, and they continued to swim towards the west. For a short period around noon the swimming speed dropped and the direction varied. Other fin whales were seen at a distance in the afternoon as K resumed heading west with its **companions. During the night, blows were mostly clustered in groups of three to five but at shortened intervals of 2 to 4 min.**

29 *June.* **Travel** speed was less **than** 1 knot from midnight to 0300 **hrs**. Swimming slowly with one companion, at 0400 hrs **K passed** within 10 m of the tracking vessel, blowing several times without lifting either tag out of water (no radio signals). The whales turned gradually toward the northwest as they resumed their travel. We were able to **observe** clearly both tag sites at 1100 **hrs** and saw that they appeared unchanged, with no sign of tissue **swelling.** K was involved in social activities at 2000 hrs with two other fin whales, splashing and rolling. One remained belly-up at the surface for 15 see, and another (not K) breached three times, after which the whales resumed traveling together. Many blows were not visible, and with little of the backs showing above water, it was **only** the radio signals that allowed the whales to be located and tracked.

30 June. After a night of mostly short (1 to 4 rein) dives with periods of both **clustered** blowing and of one or two blows per ***series,*** at 0500 hrs the submergence times lengthened. Throughout the remainder of the day the signals indicated steady movement to the west. The weather deteriorated and seas increased so that we did not attempt a close approach. The whale was moving relatively slowly (3 knots), but the track (Fig. 1) indicates a higher speed, possibly due to the influence of the **Irminger** Current. By 2000 hrs K had passed onto the **East Greenland** shelf and was at the edge of the strong, southerly flowing East Greenland Current. For the remainder of the track the whales passed back and forth across the meandering current boundary which was visibly distinct, and at which fluctuations of as much as 4°C occurred in surface water temperature.

1 July. At 0310 **hrs** K shifted **behaviour** and began long series of clustered blows with **dive sequences of up to** 16 min. There

were a number of fin whales in the area and K changed, partners. Apparent social activity occurred periodically throughout the day. We also observed near-surface activity recognized as typical of fin whales feeding on schooled fish (rapid lunges, quick turns with the whale on its side, surfacing with **mouth ajar and water** pouring through the sides of baleen). This was very different from the steady, slow feeding passes through patches of **krill** observed earlier. The ship's crew were Icelandic **capelin** fishermen and their analysis of **echo**-sounder and sonar displays indicated an abundance of **schooled capelin-like fish along the boundary** of the East Greenland Current. Feeding and social activity were followed by a period in which K appeared to be alone and resting. Then in company with 5–6 other whates, K was actively **social** again. The whales fed for short periods (20 rein) at a time.

2 ***July.*** The night (although fight enough to see well above water) continued to be a time of relatively reduced activity: shorter submergence, blows sometimes without radio signals, and slower swimming with other whales near the surface. K changed companions during the night. Dive times lengthened beginning at **0400** hrs. Social activity and apparent feeding on fish near the surface occurred throughout the day with submergence up to t6 min. For a short period K was alone and difficult to approach closely, and then was joined by 4 or 5 fin whales. These **whales** remained active throughout the night (2 –3 July), in contrast to the relative inactivity of previous nights.

3 July. Tbe number of fin whales in groups that included K varied up to seven or eight **at** different times in **the** day. Other whales were often visible **in** the distance. The activities of tbe **whales** included variable periods of swimming **close** to the surface, social activity, periods **of** longer **submergences**, and feeding **on** schooled fish (sometimes visible from **the** surface). The whales crossed and recrossed **the meandering** edges of the **East Greenland Current.**

4 *July.* At 0430 hrs the whales changed their swimming **behaviour** from predominantly near-surface swimming with other whales (one or two blows at intervals of less than 3 rein) to longer dives with clustered blowing. At 1100 hrs K was feeding with 3 other **fin** whales, and submergence times lengthened to 11 min. At 2000 **hrs** both radio tags were observed closely and photographed. They were still in good position with apparently no loosening in the tissues or changing orientation.

***5 July.* The** activities of the whales varied throughout the night, with both short and longer **submergences.** By 0300 hrs K began to move westward at 5 knots, and maintained that heading for at least the next 5 bra. The tracking ship stopped for engine repairs at 0610 hrs (final recorded position), while K continued to move' to the west. The radio signals were monitored until 0800 hrs. Both the forward and fin tags were still transmitting well when tracking was terminated.

TAG SIGNAL ANALYSIS

During the 9-day and **10-hr** track, 6519 signals from the forward tag were recorded and **1603** from the fin tag. Each signal was comprised of a series of one to eight pulses transmitted at **two** per see, when either or both tag antennas were lifted out of water during the **whale's** surfacing. Most respiration surfacings provided two to four pulses from the forward tag. During 24,6% of the recorded surfacings the fin tag also transmitted. Sometimes fin tag signals alone were received, and as noted above, occasionally K **blew** without exposing either tag antenna. A plot of **7.5-hr** segment of time showing the relationship between signals from the forward and fin tags was given by **Watkins (1981c,** Fig. 4).

The two **respiration** patterns (clustered blowing and single blowing) were apparent

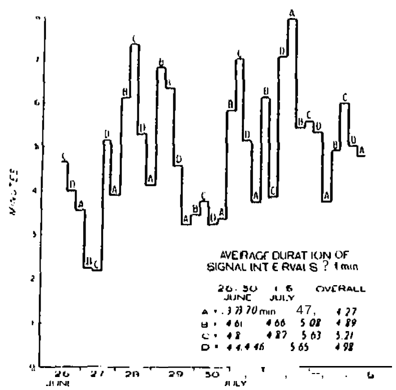

Figure 3. Average signal intervals (drew times) of 1 min or longer plotted for each of four 6-hr daily periods Period A was 2200 0400 hrs, Iceland time, which was 2 hrs off local sun time; period B was 0400–1000 hrs; period C was 1000 -1602 hrs, and period D was 1600 2200 hrs. The 1 min intervals m this figure exclude all of the short dives between blows during clustered blowing. The dive times were generally shorter during period A, the darkest period. and they were on the average longer during the lightest period, C.

in analyses nf the radio signals. During clustered blowing there were 3 10 12 blows less than 1 min apart (usually *2* to *4* blows per m in), occurring after submergences longer [ban 3 min. The average surfacing interval during clustered blowing was 0.48 min. Longer dives were generally followed by more blows. As an example of clustered blowing, on 1 July during 2 hrs and 58 rein, there were 17 dives of 5 to 12 min (averaging 8 min 18 sec) with 133 blows in clusters averaging .3,4 blows per min during the blow sequences and 1 .33 Mows per min over the 3-hr period of diving and clustered Mowing. There were 133 signals from the forward tag and 40 from the fin tag.

Single blowing (sometimes two blows) followed short submergences of 1 to 3 min when the whale appa rently re mained near the surface, and sometimes occurred over extended periods (10 hrs on '27 June, from 0330 to 134( )hrs). Single Mows were often more difficult to see; the exhalation was less visible in air, and occurring singly they did not attract as much attention as *did* cl ustered blows. During single Mows radio signals were usually transmitted only by the forward tag.

Submergence times indicated by the intervals between signals were analysed in three ways (Figs. 3, 4 and 5) to relate dive times to daily routines. Signal intervals from both tags were averaged over four 6-hr periods, beginning after the implantation of the forward tag. The times on the Figures were two hours ahead of local sun time in the Irminger Sea so that period A at 2200 10040f) hrs was the darkest period, although never totally dark in midsummer at these latitudes.

Signal intervals nf 1 min or longer were analyzed in Figure 3. This only excluded the shortest submergences, such as during clustered blowing. Without clustered blowing, the average signal interval (dive time) during all periods was 4.42 min during the first half of the track (26–30 June) which included feeding on krill near the surface and the travel across the Irminger Sea. During the second half (1 –5 July) which included more

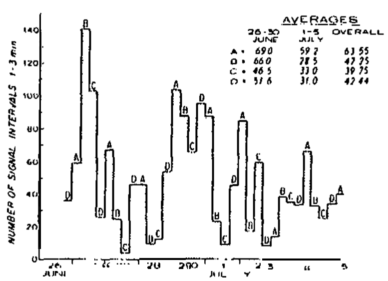

Figure 4 The number of signal intervals of 1 to 3 min duration are plotted in the. fo ur 6 hr daily periods. These shorter dives, indicating "single" blowing behaviour, occurred most often during the dark period A, in spite of differences in activity during the two halves of the track

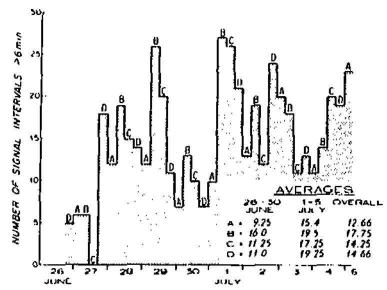

Figure 5 The number of signal intervals 6 min or longer is related to the four 6-hr daily periods. The long dives occurred least during the dark period A and most often in period B, which may be related to early morning feeding, although when considering all dives over 1 min (Fig. .3) average dive times were longer during period C.

lung dives and feeding cm schooled fish along the boundary of the East Greenland Current, the average dive time was 5.27 min. Over the entire track the dive *times* averaged 4.85 min. Including all submergences during clustered blowing, the average signal interval was 1.87 min during the first half of the track and 2.(I9 min during the second half, with an overall average of 1.98 min.

For each half of the track, the 6-hr averages of dive times longer than 1 min (Fig. 3) were generally shorter during period A, the darkest period, than during the other periods. Dive times of 1 to 3 min duration, which generally indicated single blowing behaviour, were analyzed (Fig. 4) and showed the same diel emphasis with more of these short dives on the average during the dark period A. In contrast, dive times longer than 6 min Fig. 5) occurred least frequently during period A, hut occurred most often during the early morning period B. However, when considering all dives greater than 1 min (Fig. 3), the total average dives were consistently longer by about I mind during the mid-day period C.

The ocean currents encountered along the track may have had significant effects on travel distances and calculated speeds (Table 1), since a northerly drift of 1 knot or inure was indicated by the ship's drift in the Irminger current, and the ship was found to drift at a speed of more than 2 knots to the southwest in the East Greenland Current. The high rate of travel on 1 July of 138.3 naut. miles (255.1 km) was influenced by the whale's position in the East Greenland Current (Fig. 1).

The ship's speed during the track, calculated from hourly Loran C positions, ranged from 0.13 to 12 knots. Because the tracking ship had to compensate for unanticipated changes in the whale's speed msd direction of movement, averages over several hours were more representative of the whale's speed (Tables 1-2). Daily averages of 3.5 to 6.5 knots are given in Table 1. K was always moving; *even* during resting periods there was some swimming. The average speed over the entire track (900 naut. miles over 224 hrs) was 4 knots. Highest speeds occurred during period B, averaging 5.2 knots *over* the whole track, 4.4 knots during the first half of the track while K was feeding on krill and travelling, and 6.2 knots during the second half while feeding on schooled fish and socializing. The slowest overall average speed of 3.8 knots Occurred during period A, with a low of 2.9 knots during period A in the first half of the track.

DISCUSSION

The WI IOI/OAR radio tagging system workerf well. Although the fin whales reacted to the maneuvering of the tagging vessel, neither the implantation of the tags nor their presence appeared to affect the behaviour of the tagged whale and its companions. This is consistent with our previous radio tagging experience and with conventional Discovery marking, The whales' startle reactions to missed tags and marks that strike the water has also been consistent (Ruud 1954; Watkins 1981b).

TABLE 1

Daily 2400-hr (midnight) positions of the tracking vessel are listed. The ship was usually within 2.5 naut. miles (S km) of the tagged whale. The predominant observed activity is given, and the travel distance, direction and average 24-hr speed is calculated from the positions. Nautical miles were used in measuring from the charted positions.

1980-Date (ending 2400 hrs)	*Ship's position N. Lat.*	*W. Long.*	*Whale's activity*	*Travel distance and direction (naut. miles)*	*Speed (average knots)*
25 June	63" 19'	25"49'	2200 hrs – 1st tag		
— ... ...,	63° 19'	26"03'	feeding on krill		
26 —	63" 13'	26"02'	1245 hrs - 2nd tag		
—	62"37'	25"46'	feeding and traveling	a4.9 - s	3.5
27 —	62° 08'	29"11'	travelling	110.9 – w	4,6
28 —	62° 16'	32"01'	—	91.4- w	3.8
29 —	63° 34'	33"56'	—	100.1 – NW	4.2
30 —	64" 33'	37"11'	—	114.9- NW	5.0
1 July	63" 38'	37"29'	feeding on fish, social	138.3- S	6.0
2 —	63" 33'	37° 34'	— . – –	79.9 – SE, NW	3.6
3 —	63"53'	36° 47'	— _ – —	70.3- NE	3.5
4 —	64" 13'	35"52'	social	104.4 – E	4.3
5 —	64° 07'	36° 09'[1]	feeding on fish, social	18.0 – N, NE	3,6

[1]) Position at 0610 hours. Tracking terminated at 0800 hours.

Although the radio signals from the tags on K allowed good tracking even in periods of low visibility and rough weather, accurate assessments of the relative signal direction was required to maintain contact. Rapid changes in speed, meandering courses, and abruptly lengthened submergence that were typical of K's behaviour, made tracking demanding.

Long periods without signals from the fin tag emphasized the importance of proper tag placement for consistent tracking. If we had relied only on signals from the fin tag, with silent periods of up to 2½ hrs, the whale could have moved 40 km or more during that time. If the whale reversed course (as it sometimes did), the distance from it would have doubled, and tracking would have been impossible. The forward tag provirfed signals during most blows, at intervals of usually less than 15 min. during which time the whale was within a manageable tracking distance of about 2 naut. miles.

During short submergence K's dives were probably shallow because the length of time would not have allowed it to go deeper. Longer dives could have been deep, but our previous observations of fin whale activity have associated most long dives with particular activities such as subsurface feeding (Watkins 1981c). This was noted also by recent sonar tracking of fin and humpback whales (Watkins and Goebel, 1984) where both short and long dives were to about the same depths.

The frequency of long dives shown in Fig. 5 is worth noting here, since there appears to be a lower frequency of long dives during period A (night) than during each of the periods B and D (morning and evening). (Wilcoxon's two-sample test gives $p<0.1$ when A and B are compared, and $p<0.2$ for A and D). Nemoto (1957, 1959) observed increased stomach contents in North Pacific fin whales caught during morning and evening hours. He remarked that this tendency

might be attributed partly to the clear diurnal migrations of the' zooplankton as prey of the whale. *Meganyctiphanes norvegica*, the most common euphausiid species taken by fin whales caught west of Iceland (Rörvik et al. 1976; Lockver and Brown 1978), generally occurs at O– 100 m depth during night and at 100–400 m depth during day (Mauchline 1980). In general capelin *(Mallotus villosus)* show similar diurnal vertical movements and are most commonly found at 0–100 m during night and at 200-300 m during daylight hours, although deviations from this may occur in summer (Vilhjálmsson, pers. comm.). It therefore appears that the most active feeding period of the fin whale is linked to the period when enough food is in the upper layer (not necessarily the greatest abundance) and some visual cues occur simultaneously, i.e. right after sunrise before the prey moves down, and during the upward movement of the prey in the evening. Thus K's long-dive rhythm, especially in the morning but also in the evening, may be related to more active subsurface feeding at these times. The same applies to the fast swimming behaviour (see Table 2), particularly during period B when the whale was actively feeding on schooled fish. It may be added that if the long dives denote active feeding as proposed, then K and his companions may have fed some during the passage across the Irminger Sea.

The diel differences in dive times match our previous radio-tagging results in which fin whales, humpbacks, and Bryde's whales made shorter dives at night, apparently resting and moving near the surface (Watkins et al. 1979; Watkins et al. 1981). It was interesting that there were these night-time speed and dive differences in the Irminger Sea although the sky was never really dark. The lack of darkness may account for the continuing activity during some nights and less marked diel differences. Although the differences were small, the lowest average speeds" were generally at night, as was the greatest number of short dive sequences with single blows. With increasing morning light, the whales generally became more active, speeds increased, blows were clustered, and dives lengthened. Although the

TABLE 2

Average speeds (in knots) over 6-hr periods, calculated from the ship's positions. Although the differences were small, the lowest (period A) agreed with diel differences in activity reflected by dive times. Note the differences between averages for the first half (feeding on krill and travelling) and the second half (feeding on fish and socializing).

	2200–0400 hrs A	*0400–1000* B	*1000–1600* c	*1600–2200* D
25/26 June	2.5	2.1	4,2	4.3
27 —	4.0	7.5	4.1	4.1
28 —	2. t	3.4	4.s	3.7
29 —	2.5	4 . 9	3.8	5.4
30 —	3.0	4. t	5.1	6.8
Track's 1st half average	*2.9*	*4.4*	4.4	4.9
1 July .	6.8	6,5	5.5	4.0
2 —	6.2	5.5	3.4	2.5
3 —	3.3	6.7	2.7	2.2
4 — . .	5.2	6.0	2.3	3.9
5 — .	2.8			
Track's 2nd half average . .	*4.9*	6.2	3.5	3. *I*
A v e r a g e overall	3,8	5.2	4.0	4.1

longest dives occurred during period B, the overall dive time live.rages were longer in period (' indicating consistently more activity during daylight.

Sudden shifts in K's activity from clustered blowing to single blowing were made obvious by the radio tracking. A surfacing behaviour characterized by readily visible blows, often at rates of 2 to 4 per min and high round-outs, could suddenly change to behaviour that was poorly visible, with faint blows 1 to 3 min apart with up to 0.5 km (at 10 km/hr) between surfacing and very little of the body showing. These behavioural shifts may explain why fin whales often seem to suddenly disappear or appear in an area

The variations in behaviour throughout the different segments of the track were interesting. K changed from feeding with companions on an abundant supply of krill, travelled for four days with a variety of other fin whales, then again fed on schooled fish and was in social contact with more companions. The motivation for such travel may have been due [0 social factors rather than food abundance or preference. K is the first proof of cast-west movement of a fin whale in the Irminger Sea and an additional indication of mixing of fin whales between Iceland and East-Greenland waters. Both K and one of the Discovery-marked fin whales off East-Greenland, that was captured oft Iceland only one week after marking (Jonsgård and Christensen 1968), show that mixing may just as well take place by quick passages across the Irminger Sea as by gradual movement throughout the season.

Radio tracking is a promising means for studying the movements and local identity of whales as well as enabling accurate, detailed assessments of behaviour. Visual identifications even of the most easily identifiable cetaceans (as for humpbacks, see Katona et al. 1979) do not provide the continuous unequivocal identifications needed for monitoring whale activity. The radio tag allowed confident tracking over long periods and provided positive information about each surfacing. The ability to maintain contact and continue to obtain accurate details of the whale's behaviour was not confined just to close observations and times of good visibility, but the same information was obtainable when the tagged whale could not be seen at a distance, in rough seas, and during periods of low visibility. In addition to surfacing information, telemetry of environmental and physiological parameters could also be easily added to the radio beacons to provide much more complete pictures of whale activities. Our continuing development of more than 20 years (Schevill and Watkins 1966) has provided new information about whales with each tagging experiment. This Iceland to Greenland track of an open sea fin whale was especially productive, the track and continuous behavioural data could not have been obtained except by radio tagging.

CONCLUSIONS

1) The fin whale "K" was not bothered by the tag.
2) Tagged and non-tagged fin whales behaved similarly.
3) The whale's movements were not influenced by the tracking ship.
4) K was difficult to approach when alone.
5) Fin whale associations were fluid, with much changing of companions.
6) Social activity may have been a primary interest: K stopped feeding, travelling, and resting to interact with other whales.
7) Diel changes in activity (speed and duration of dives) occurred in spite of less (ban total darkness at night.
x) Feeding methods varied with changes in prey
9) Fin whales at sea were often difficult to see, especially during single blowing behaviours.
10) The mixing of fin whales across the Irminger Sea may take place by quick passages between East-Greenland and Iceland, as well as by gradual movement throughout the season.

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RADIO-TELEMETRIC STUDY AND AERIAL CENSUS OF GRAY WHALES IN THE CH ANNEL ISLANDS NATIONAL MARINE SANCTUARY DURING THE SOUTHWARD MI(XATION, JANUARY 1986

by

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ABSTRACT

The Channel Islands National Marine Sanctuary (CINMS) is a tract of ocean, about 1,252 rim', encompassing the waters within 6 nm of San Miguel, Santa Rosa, Santa Cruz, and Anacapa Islands, running east and west, and Santa Barbara Island to the south. This island system is uniquely positioned in the Southern California Bight, being the firat islands south of Point Conception where the mainland coast turns east toward Santa Barbara. From January 18 to February 4, 1986, s pilot study was conducted in the CINMS with the overall goal of producing baseline information on gray whales (Eschrichtius robustus) during the peak period of their southward migration; two techniques, aerial surveys and radiotelemetry, were employed.

Strip-surveys were flown to determine the abundance, distribution, behavior, and resource use of gray whalea throughout the CINMS. For strip-surveys, two replicates were flown of a systematic grid of north-south transects spaced 4 nm apart. On each replicate, requiring 6-hrs to complete, we surveyed 265.46 nm' of water, an estimated 25% of the surface area of the sanctuary. Survey 1 (on January 20 and 21) produced 32 sightings totaling 67 whales and 8 calves, Survey 2 (on January 21, 24, and 25) produced 23 sightings totaling 61 whales and 9 calves, and the average count was 64 whales and 8.5 calves. Based on these data, the ratio of means estimator (modified) yielded a population estimate (corrected for submerged whales) of 676 ± SD 206 whales in the CINMS during Survey 1, and 613 ± SD 211 whales during Survey 2, with a mean est imate of 643 ± SD 173 whales (95% C.I. 583, 703). Animals clearly identifiable as calves of the season comprised 13.3% of all grays seen

during strip-surveys. The abundance of calves (uncorrected) was estimated at 32 ± SD 15 for Survey 1, and 36 ± SD 15 for Survey 2, with a mean estimate of 34 ± SD 11 calves (95% C.I. 30, 38).

A near-shore aerial survey (100% coverage) was flown on January 20 and 24 to document the numbers, distribution, and behavior of whales within 0.75 nm of the sanctuary islands. Twenty-nine sightings totaling 58 whales and 2 calves were observed; an additional 22 whales and 1 calf were sighted on connecting flights between the northern islands.

Gray whalea were observed throughout the CINMS, but they were primarily distributed within waters 3 nm or leaa from the island shores; during strip transects, for example, 94% of the mother-calf pairs and 91% of the whales without calves were within 3 nm of shore. Although the mean distance from shore for both groups was similar (1.53 ± SD 1.14 nm versus 1.95 ± SD 1.09 nm, respectively), mothers and calves were generally nearer to shore than were whales without calves; 82% of the mother-calf pairs were within 2 nm of shore compared to 58% of the whales without calves. In relation to water depth, 60% of the mother-calf pairs were in water 30 fm (55.4 m) or less in depth, while the remaining 40% were in waters up to 300 fm (548.6 m) deep over the Santa Cruz Canyon. The majority of the whales without calves (86%) were in waters up to 50 fm (91.4 m) deep. Overall, there did not appear to be a strong trend for whales to prefer a particular bottom type. Areas where whales tended to cluster included the channels between the northern islands, particularly Santa Cruz Channel, and points, reefs, and headlands including Point Bennett, Beacon Reef, West Point, and Cavern Point. Locations where few or no whales were seen included the south side of San Miguel Island, the southeast side of Santa Rosa Island, the north aide of Middle and West Anacapa Island, and the east side of Santa Barbara Island.

The predominant behavior of all gray whalea observed during aerial surveya was traveling (70% of mother-calf pairs and 73% of whales without calves); but mothers with calves traveled more slowly than other whales. Overall, directional preference was southeast for whales without calves (64%), east-southeast for mother-calf pairs (29% E, 21% SE), and appeared related to the direction of the southward migration. Courtahip and mating, seen for 42 animals, comprised 22% of the behavior of whales without calves. Resting and milling were seen for 25% of the mothers and calves, compared to 2% of the other whales. Potential feeding waa seen for 3% of whales without calves and 5% of mother whales; apparent feeding was observed 5 times within kelp beds and once over a sand bottom. Group size varied from 1 to 14 animals, with most whales without calves in pairs or groups; 22% were lone animals, 19% were in pairs, 18% were in trios, and the remaining 41% were in groups of from 4 to 14 animals. In contrast, each of the mothers was alone with her calf. Twenty-three instances of disruption to whales due to the activities of commercial whale-watching boats were observed.

Radiotelemetry was used to track gray whales over 24 hour periods to determine their day and night travel rates, inter-island migration routes, duration of stay, local movements, and behavior in the CINMS. Nine whales were tagged from January 21 to February 1 with a small (1.5 cm by 6 cm), implantable, capsule radio-tag applied with a crossbow. Each whale was tagged, monitored, and tracked from a 68 ft motor-sailer until the whale exitad from the CINMS (6 cases), or its radio signal was lost (3 cases); locations of whales were also determined using receivers aboard aircraft. Daytime and nighttime rates of swimming (i.e. southward migration rates) were not significantly different. During 29.96-hrs of daylight tracking, the 9 whales traveled at a mean rate of 3.02 ± SD 0.44 kts (5.59 ± SD 0.81 km/hr) with a range from 2.11 to 3.65 kts; during 25.5-hrs of nighttime tracking, the whales traveled at a mean rate of 3.45 ± SD 0.45 kts (6.39 ± SD 0.83 km/hr) with a range of 2.99 to 4.19 kta. The overall mean durat ion of surfacings waa 2.05 ± SD 0.73 sec, ranging from 0.29 to 4.5 sec (n = 1,530). Short divea (< 1 min long) comprised 46% of all dives and averaged 30.28 sec ± SD 12.83 sec, with a range from 3.95 to 59.84 sec (n = 702). The mean length of long dives (≥ 1 min) was 3.06 ± SD 2.17 min, ranging from 1.00 to 28.08 min (n = 828). The minimum duration of stay within the CINMS varied from 3.9 to 60.7 hrs for the 6 whales that were monitored until their departure. In the northern portion of the CINMS, gray whales migrated along both the inner leeward-side (north) and the outer weather-aide (south) of San Miguel, Santa Rosa, Santa Cruz, and Anacapa Islands; three inter-island routes were documented for southward migrants. Finally, 6 of the 9 grays radio-tagged from January 4 to 18, 1986 during the National Marine Mammal Laboratory sponsored study near Granite Canyon, California were relocated a total of 17 times within the CINMS. The time from the last detection of these whales off Central California to the first detection in the sanctuary ranged from 3 to 14 days. Radio signals were received from these whales over 1 to 4 day periods within the CINMS.

The occurrence of other cetaceans was documented opportunistically. 'There were 26 sightings of 4 odontocete species rrnd 15 sightings of unidentif ied dolphin species, totaling 4,098 animals. No attempt was made to estimate the size of these populations.

Recommendations for future work conclude this report.

Final Report For

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DAY AND NIGHT MIGRATION RATES OF RADIO TAGGED GRAY WHALES (Eschrichtius robustus) ALONG THE CENTRAL CALIFORNIA COAST

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ABSTRACT

Daytime and nighttime migration rates of gray whales (*Eschrichtius robustus*) were documented *to* verify population **estimates** based on **daytime** shore census **counts** which are extrapolated to represent the number of whales passing the census site, during entire 24 hr periods. It has been assumed that there is no diurnal change in the rate at which gray whales migrate past the census station. To test the hypothesis thst the whales ' day and night swimming rates were similar, nine gray **whales** were radio-tagged and tracked as they migrated south along s 70 **nm** portion of the central California *coast* **from Point Piños (36°37.O'N, 121°55.O'W)** to Point Piedras **Blancas (35°39.O'N,** 121 °17.O'W).

The net rate of daytime travel for the nine radio-tagged whales ranged from 1.91 to 4.27 kts (3.54 to 7.91 **km/hr)** with s mean rate of 3.23 ± SD 0.70 kts (5.98 **km/hr)** and a 95% **C.I.** of 2.73-3.73 kts (5.05-6.91 **km/hr).** During the night, their migration rates ranged from 2.56 to 3.91 kts (4.74 to 7.24 **km/hr)** with a mean rate of 3.34 ± SD 0.50 kts (6.18 **km/hr)** and a 95% **C.I.** of 2.96-3.73 kta (5.48-6.91 **km/hr). When** compared as two groups, the day and night migration rates were not significantly different (ts= 0.389, P > 0. 50), suggesting that census estimates based on daytime shore counts need not be corrected for nocturnal changes in ❑igration rate. The **overall** mean ❑igration rate waa 3.31 ± SD 0.62 kts (6.13 **km/hr)** with a **95% C.I.** of 3.01-3.61 kts (5 .57-6 .68 **km/hr).** These migration rates are compared with previous studies.

The frequency and length of surfacings and dives for each radio-tagged whale are presented. The surfacing and dive data indicated thst a whale 'a mean surface interval was 1.34 min. and the mean length of it's long dives was 3.10 ❑in, suggesting that a southward migrating whale spends approximately 70% of its time below the surface during deep dives.

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INTRODUCTION

The recovery of the northeastern Pacific stock, or California-Chukotka population of gray whales (Eschrichtius robustus) from severe depletion at the turn of the century has been touted as a marine wildlife management success atory (Rice and Wolman, 1971; Jones et al., 1984). The trends in abundance of this population from 1967 to 1980 suggest that the California-Chukotka population is the only stock Of large cetaceans that has continued to increase 2.5% per year concurrent with an annual exploitation rate of 1.2% (Reilly, 1981). Nevertheless, the accuracy of gray whale population estimates and the assumptions of the models utilized to monitor trends in the population size and dynamics of this species were questioned at the 1985 meeting of the Scientific Committee of the International Whaling Commission (IWC). Concern was expressed as to the adequacy of estimates for life history parameter used in quantitative models used to predict rates of population growth in gray whales, and for a greater than twofold difference between current population estimates from different portions of the gray whales ' range (IWC, 1986).

Estimates from shore censuses conducted during the southward migration between 1978 and 1985 range f rnm approximately 15,000 to 18,500 animals (Breiwick et al., 1985; Herzing and Mate, 1984; Reilly, 1981, 1984; Rugh, 1984), while the most current estimate of the number of gray whales wintering in Baja California from an aerial census of the winter grounds in 1981 was 7,600 whales (Rice et al., 1983). This difference raiaed questions concerning the interpretation Of the apparent abundance trends for the population as well as the accuracy of the abundance estimates on which the trends were based. The accuracy of the models used to analyze gray whale population trends is only as good as the accuracy of the population estimates themselves, and with gray whales, the accuracy of the population estimates is a function of the underlying assumptions used to develop the estimates from census counts,

The analysis of abundance trends for this population is of paramount importance because it haa been proposed that the gray whale be removed from the endangered species list, and the basis for such a decision is the apparent recovery of the population (National Marine Fisheries Service, pers. comm.). Additionally, the IWC utilizes abundance estimetes to regulate the take of these whales, and to analyze population trends.

Because shore based counts of whales passing the census station during the daytime are extrapolated to account for whales pasaing during the night, and because there is little data to support the assumption that gray whales migrated at the same rate during the night as was observed during the day, the extrapolation of daytime counts to account for whales traveling past the census site at all hours was thought to be the weakest link in the formulation of abundance estimates (Reilly, 1984). Biases in the abundance estimates could be the result of errors in this underlying assumption, that is, that during migration gray whales may vary their swimming speed at night rather than maintaining a constant rate of movement.

To investigate possible diurnal changes in swimming speed. the National Marine Mammal Laboratory (NMML) sponsored a radio-tagging program to document daytime and nighttime migration rates of gray whales during their southward migration along the central California coast as the most direct method for verifying population estimates based on shore censuses. This program coincided with the 1985/1986 shore census conducted by the NMML at Granite Canyon, California.

The overall objectives of this research were:

1. to obtain data on gray whale day and night migration rates to determine if significant diel variations exist, and how these variations could affect the estimation of population size from shore-based daytime counts (the null-hypothesis tested would be that there is no significant difference between daytime and nighttime migration rates), and,

2. to evaluate the use of short-term VHF radio-telemetry devices for the study of local movements and other behaviors of large cetaceans, including but not restricted to gray whales, and the effectiveness of radio-tracking as a tool for marine mammal management.

Immediately following this study, a companion project was conducted to survey the abundance, distribution, and movements of gray whales through the Channel Islands National Marine Sanctuary in the Southern California Bight (Jones and Swartz, 1986). Nine whales were tagged and tracked in the Sanctuary, and these findings are compared with the results from whales tagged and tracked off the central California coast.

BACKGROUND

The Problem

At the summer 1985 meeting of the Scientific Committee of the International Whaling Commission several questions were raised concerning current estimates of gray whale abundance and recent population trenda, and the techniques utilized to formulate these estimates.

In their psper "An Age Structured Population Model Applied To The Gray Whale" Lankester and Beddington (1985) stated that if normal density dependent mechanisms are operating, the gray whale population waa likely to be decreasing under the present catch regime, rather than increasing at 2.5%/yr as determined by Reilly et al. (1983). They further stated that since gray whales received protection the present population should have attained carrying capacity (K) rather than continuing to increase unless (1) the unexploited stock suffered a greater aboriginal take than hae been estimated, (2) K for gray whales mny have changed in the past 200 years, or (3) that the 19th century take estimates were much greater than calculated from historical data. Unfortunately, there were insufficient data to resolve these questions. Cooke (1985) identified what he felt were "points Of uncertainty" in the estimates for life history parameter ueed to calculate net recruitment rates in gray whales, and stated that it waa difficult to reconcile recently estimated population estimates and rates of increase with the standard model of a population recovering from pest exploitation under

the influence of density dependent factors. He concluded that the present gray whale population may not be increasing, and that estimates of net recruitment rate in the gray whale do not provide a useful guide to estimating recruitment rates in other baleen whale species.

Al though the Scientific Committee acknowledged that the present gray whale data base has shortcomings, in light of recent observations of gray whales in areas of the Gulf of California that they occupied prior to their depletion by the whaling industry (Findley and Vidal, 1983; B. Tershey, pers. corn. ; J. Urban, pers. tom.), relatively stable counts of gray whales in the breeding lagoons of Baja California during studies over the paat aeven years (Bryant et al., 1984; Fleischer et al, 1984 ; Jones and Swartz, 1984), and the consistency of population counts from the Monterey (Granite Canyon) ahore census program between 1967 and 1980, the relative abundance of gray whales was thought to be indicative of the recovery of the stock from depletion, The Committee could not resolve, however, whether the population wae decreasing, increasing, or stable at this time.

Clearly an additional census and a program to obtain current data on the number of gray whales passing shore census stationa during all houra of the day and night were needed to verify the population estimates used to analyze abundance trends for. the northeastern Pacific gray whale population. Attempts to census the population in Mexican waters were felt to be ineffective because during the winter the population is scattered over a large geographical area all of which has not been adequately investigated, and because a census of the entire winter range would be logistically difficult and not coat effective. In addition, studies of the ratea of travel between lagoons and the duration of stay of individual whales within the breeding lagoons further suggest that at any given time during the winter a substantial proportion of the population may reside in areas other than the outer coast of Baja California and within the breeding lagoons (Jones and Swartz, 1984).

Shore based censuses during the annual migration were thought to have the greatest potential for estimating the population size provided that the location of the census site was one where moat if not all of the population waa known to paas during its migration. The Unimak Pasa census site (Rugh, 1984) was thought to be unsuitable because a recent review of the literature (Jones et al, 1984) suggested that an unknown proportion of the population does not spend the summer in the Arctic, but resides along the shores of Northern California, Oregon, Washington, Canada, and Southeast Alaska. Thus, the central California census site at Granite Canyon was thought to be the best available site because most 'f the population apparently passes this location during the southward migration (Herzing and Mate, 1984; Reilly, 1984; Jones and Swartz, 1984), and because there were 14 years of counts at this site for comparison with a census planned for the 1985-86 migration.

Population Estimates from Shore Censuses

The "best estimate" of the size of the northeastern Pacific gray whale population comes from the analysis of 15 annual shore censuses of the southward migration conducted. firat at Yankee Point and then at Granite Canyon, near Monterey, California from 1967 to 1986 (Reilly et al., 1983; Breiwick et al., 1985; Breiwick and Dahlheim, 1986). During the 13 years beginning in 1967, the population was estimated to increase exponentially at 2.5% per year from approximately 11.285 whales to 15,647 whales in 1980. More recent estimates were 18,477 whales in 1985, and 14,658 whalea in 1986 (the 1986 estimate did not include a correction factor for animals missed as a function of their distance off shore, which would have corrected this estimate upward; Breiwick, pers. comm.).

The major assumption of the population estimates from daytime shore censuses has been that whales migrate at constant speede Over 24-hr periods and that most if not all of the population passes the census station during the census period (Reilly, et al. . 1983). Because it is necessary to interpolate approximately 58% of the total migration due to dsrkness, the most likely source of bias within these estimates is variation in nighttime migration rate, which directly effects the estimation of the number of whales passing a shore station at night (Gilmore, 1960; 'Reilly, 1984). If gray whales slow their migration rate significantly at night, the existing population estimates would be biased upwards. Reilly (1986), for example, suggests that if gray whalea slow down at night to one-half their daytime migration rate, a population estimate of 11,083 whales would be calculated for 1980 compared to 15,647 when a continuous 24 hour swimming rate is assumed. Similarly, if the whales increase their migration rate at night, the present population estimates would be too low, and not account for the actual number of animals passing the census station.

Radio Tagging Technology and Its Use with Cetaceans

Radio-tracking is an indispensable tool for the study of elusive species such as cetaceans because individual whales are difficult to identify, they travel for prolonged periods out of sight underwater, and generally are visible at the surface for only short periods during daylight hours (weather permitting). Continuous observations of whale behavior have traditionally been restricted to daytime, and little or no information has been obtained on the nocturnal activities of cetaceans. With the development of radio-telemetric devices it is now possible to gather continuous 24 hr information on the location of individual whales, their movements, rates of travel, surface intervals, and their duration of dives (Leatherwood and Evans 1979).

Recent research on cetacean movements utilizing radio-tags include studies of humpback (Megaptera novaeangliae) and fin whales (Balaenoptera physalus) (Watkins et al. 1978; Goodyear, 1985) and Bryde's whales (Balaenoptera edeni) (Watkins et al. 1979). Several species of odontocetes have been captured, fitted with radio devices, released, and tracked; these include killer whales (Orcinus orca) (Erickson 1977), pilot whales (Globicephala scammoni Cope) (Evans 1974a) , and several species of dolphins (Evans 1974a, Leatherwood and Ljungblad 1979, Wursig 1979, Jennings and Gandy 1980).

Studies with gray whales have shown them to be good subjects for radio tracking because they are more accessible than pelagic cetaceans. Because of their proximity to the shore during migration, and because nf their occupation of shallow lagoons in Baja California, researchers may

approach numerous whales in relatively localized geographical areas. Norris and Gentry (1974) captured suckling gray whale calves in Boca de Soledad, Baja California, Mexico and attached transmitters with flexible harnesses and timed-release mechanisms (Norris et al. 1977). Sweeney and Mattsson (1974) surgically attached a 27-MHz radio transmitter to the dorsal ridge of a captive yearling gray whale that was collected in a breeding lagoon, maintained for a year in captivity, and then released and tracked as it migrated along the coast of California by Evans , (1974b).

The moat ambitious radio-tracking program with gray whales was conducted by Mate and Harvey (1984) and Harvey and Mate (1984) in San Ignacio Lagoon, Baja California Sur, Mexico. Between 1979 and 1980 they applied 18 radio-tags to adult whales and successfully tracked the movements of these animals following their departure from the lagoon. In addition to migratory movements, these studies generated data on dive durations, surf ace intervals, and rates of movement., as an average daily swimming apeed (overall for day and night travel combined).

In a preliminary study of gray whale migration during the 1984/1985 winter, Swartz and Harvey (1985) utilized modified pinniped radio-tags to track two southward migrating gray whales past Monterey, California and along the Big Sur coastline during the day and night. They obtained accurate measurements of hourly rates of movement, duration and frequency of surf acings and dives, the percent of time the whales apent at and below the surface, and their dive/surface patterns. The findings of this study clearly demonstrated that miniaturized radio transmitters had great potential to gather data on gray whale nighttime versus daytime migration rates for the verification of population estimates presently based solely on daytime observations, and to gather information on gray whale nocturnal behavior for comparison with the large body of information that presently exists from daytime studies.

METHODS

Study Site

Southward migrating gray whales were radio-tagged along the Monterey coast between Point Piños (36°37 'N, 121°55 'W) and Point Sur (36" 18'N, 121°54'W), and their movements were monitored as they swam couth along a 70 nm (130 km) portion of the central California coast terminating at" Pt. Piedras Blancas (35°39'N, 121°17'W) (Fig. 1). This area was selected because numerous gray whalea migrate within 1-1.5 nm (2-2.8 km) of the shore throughout the month of January, and this portion of the coastline included the location of the Granite Canyon Marine Laboratory (10 nm south of Monterey) which was utilized by the NMML to conduct the 1985/1986 shore census concurrent with this study.

Radio Tagging and Tracking

The radio-tag ueed in this study was developed by J. Goodyear (Ecological Research Associates, Inc.) . Each tag contained a two-stage VHF transmit ter and battery housed in a 1.5 cm by 6 cm stainless steel cylinder with a 45 cm braided stainless steel whip antenna encased in

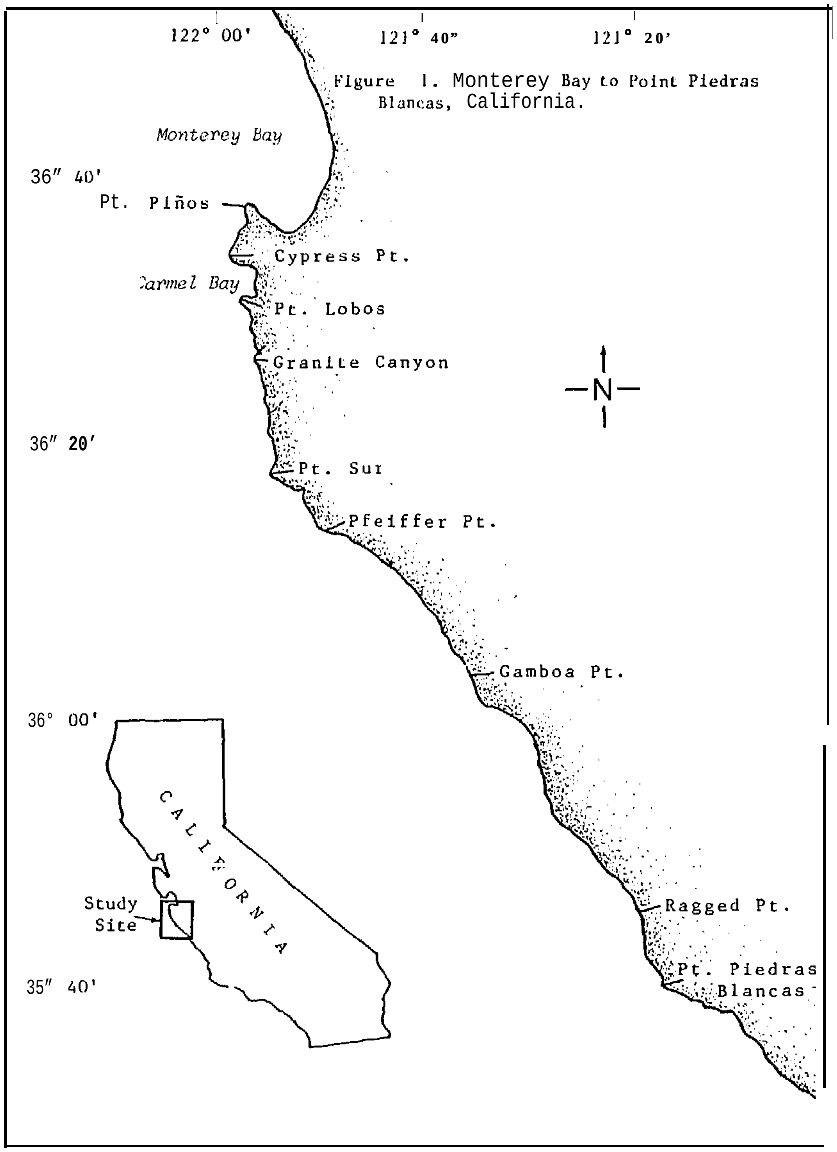

Figure 1. Monterey Bay to Point Piedras Blancas, California.

plastic beat-shrink tubing protruding from its posterior end (Fig. 2 Top). These tags emitted a 10 mW signal with a 20-25 msec pulses on discrete frequencies between 148 and 150 MHz, and hod a life of approximately one month. The capsule tag is designed to embed itself in the whale's skin and blubber leaving only its antenna protruding. The tag was pointed and had four stainless steel blades on ita anterior end to penetrate the whale's skin on impact. Six wire barbs on the sides of the capsule prevented it from dislodging after penetration.

Each radio-tag was attached by friction fit to an aluminum arrow shaft and was delivered to the whale by crossbow. Upon impact with the whale, the tag separated from the arrow leaving only the tag's antenna protruding from the skin. A freshwater spinning reel was mounted on the crossbow, and a monofilament fishing line was attached to the arrow so that both the tag and arrow could be retrieved if the target was missed (Fig. 2 Bottom). Because optimum transmission of the radio signal required that the tag antenna be as nearly vertical as possible, delivery of the tags from above the swimming whales was necessary to provide the best tag placement. To accomplish this the tags were applied to the whales from the bow of a 68 ft (21 m) motor-sailer, the "Diamaresa", which was equipped with a sword-fish bowsprit that provided a tagging platform 16-19 ft (5-6 m) above the water in front of the vessel (Fig. 3).

To track the whales, the vessel was equipped with an array of two 5-element 9 dB gain antennas (Teleonics RA4-A)[1] mounted atop the foremast approximately 50 ft (15 m) above the deck and oriented 180 degreea apart; one antenna was oriented forward and the second aft of the vessel. A third 3-element 6 dB gain Yagie antenna (Teleonics RA-2A) was mounted on a 13 ft (4 m) mast that could be rotated 360 degrees to locate the signal source relative to the vessel's position (Fig. 3).

These antennas were connected to telemetry receivers (Telonics TR-2) capable of receiving transmission in the frequency range of 148 to 150 MHz, which were connected to frequency scanners (Telonics TS-1) that could be programmed to search for several radio-tag frequencies simultaneously, and to signal processors (Telonics TDP-2) which provided measures of received signal strength and pulse width (Fig. 4 Top). Two receiving systems were operated during tracking. The first system included a telemetry receiver connected to the two formast antennas via a switch-box (Telonics TAC-2) that allowed each antenna to be isolated from the other and operated separately, or for both antennas to operate together to scan both forward and aft simultaneously. The second system included an identical receiver connected to the 3-element antenna to locate the position of a tagged whale relative to the vessel.

Both receiving systems were monitored continuously during tracking. As radio transmissions were received, the time of each surfacing and its length (recorded as the number of pulses received) were entered into a Compaq Portable Computer which then calculated the length of the surfacing and the length of each subsequent dive (Fig. 4 Bottom). Additional data collected during daytime hours included the behavior of the tagged whales, and, when in a group, the number and behavior of the whales in the group which included the tagged whale.

The vessel's Loran-C navigation system was used to progressively plot whale positions relative to the vessel as they moved through the study area. To estimate the distance from the vessel to tagged whale (i.e. , the signal

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[1] The use of trade names in this report is for documentation purposes only, and does not imply an endorsement by the authors ...

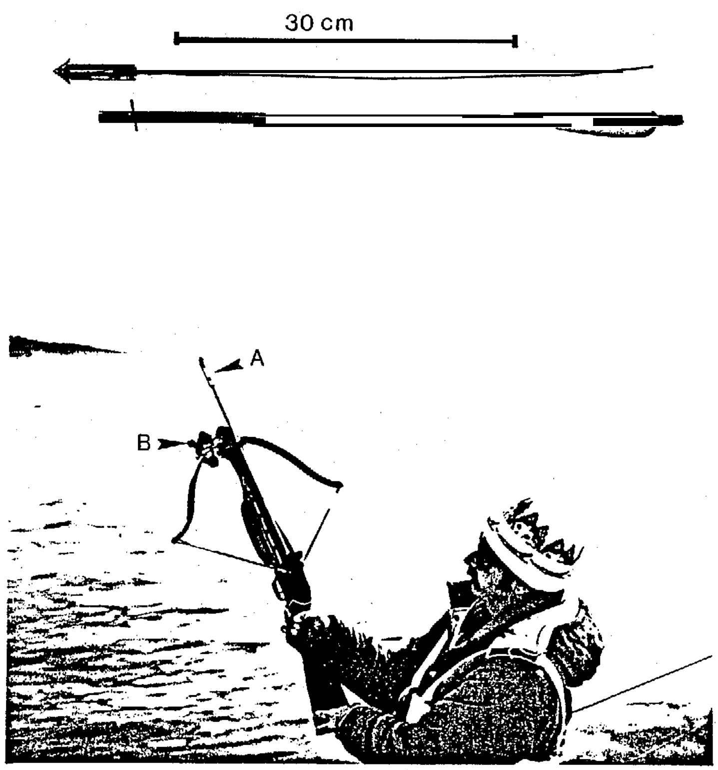


Figure 2. The "capsule" radio tag designed by J. Goodyear (Ecological Research Group, Inc.) showing the transmitter (pointed cylinder), with its antenna, and the hollow crossbow arrow upon which it was mounted (top), and the crossbow (bottom) showing the transmitter (A) and the fishing reel (B) mounted on the crossbow to retrieve the tag/arrow when the target was missed.

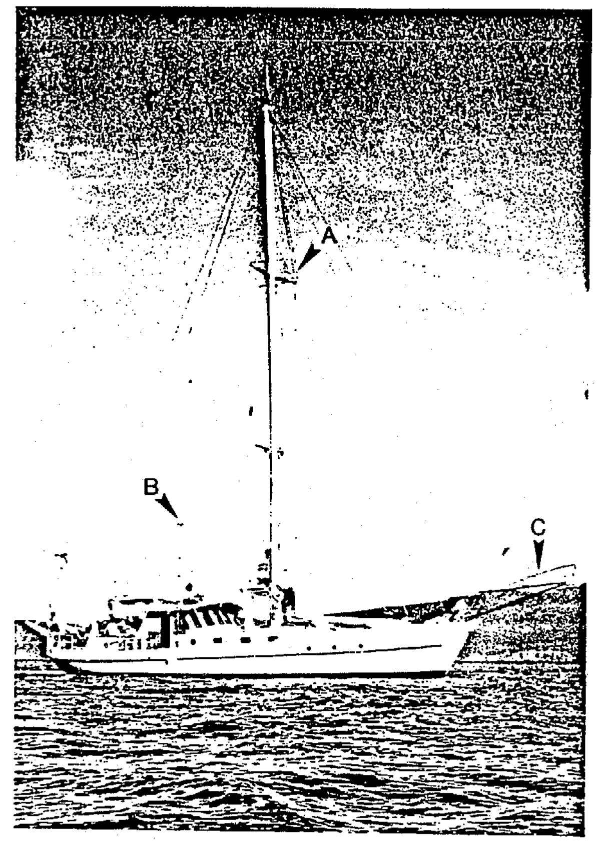
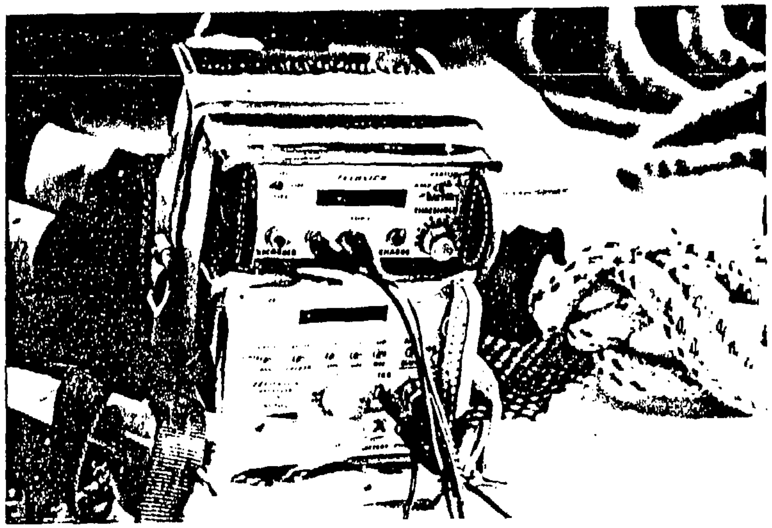


Figure 3. The radio-tagging vessel "Diamaresa". Pointers show the position of the 5-element radio-telemetry antennas on the main mast (A), the position of the 3-element directional antenna (B), and the 2.5 m catwalk extending over the bow from which the radio-tags were applied to the whales with a crossbow (C).



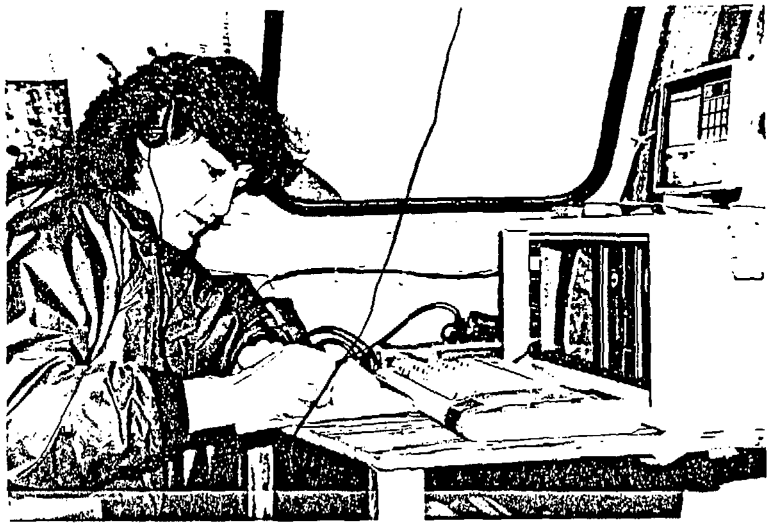


Figure 4. Telonics radio-telemetry receiver, frequency scanner, and a signal processor used to track the radio-tagged whales (top), and shipboard Compaq Portable computer used to record incoming telemetry data (bottom).

source) during the night, the correlation between received signal strength and distance between the whale and vessel was first determined during the day as follows. The signal processor (Telonics TDP-2) connected to each receiving system provided a measure of received signal strength in decibels. While in visual contact, the distance from the vessel to a tagged whale was estimated when the whale surfaced, and this distance was compared to the strength of the signal received during each surfacing. At night the received signal strength alone was then used to estimate distance between the tagged whale and the vessel. In general a distance of 0.5 to 2.0 nm (about 1-4 km) was maintained between the tagged whale and the vessel during a tracking episode to minimize the potential influence of the vessel on the whale's behavior.

Two vehicles equipped with receiver/scanner systems (Telonics TR-2 with 2-element Yagie antennas Telonics RA-2A) were also utilized to monitor signals from the tagged whales as they moved along the coast. Both of the mobile tracking teams were in radio contact with the vessel during tagging operations. When a tag had been successfully app Lied to a whale, the responsibility for following the whale was transferred to one of the mobile shore teams, freeing up the vessel to attempt to apply another tag. The mobile team then followed the radio signal from point-to-point as the whale moved progressively south along the coast. At each location, the team monitored the signal until it beceme too weak to be reliably documented. The period of maximum received signal strength was used as an indicator of the time that the whale passed each specific location. Shore teams also recorded the time and duration of each surfacing and dive while monitoring the radio signals. Once a signal became weak, the mobile team moved several miles south until a strong signal was re-encountered, and then repeated the tracking process at that location. The mobile teams followed each tagged whale until sunrise or until the whale reached Pt. Piedras Blancas at the southern end of the study area.

Analysis

Data from the vessel and the shore teams were used to determine each whale' a direction of swimming, distance traveled. and migration rate. Behavioral data recorded from each tagged whale included frequency and length of surface intervals and of dives during all hours that the whale was monitored, and from these, surface and dive patterns were determined. Because these data were obtained continuously during all hours, comparisons of day and night behavior were possible.

RESULTS

Radio-Tagged Whales: Individual Cases

For each gray whale that was radio-tagged and tracked, a narrative of the date, time, and location of tagging, and a description of the whale's behavior and migration route, including a comparison of its daytime and nighttime rate of travel are presented first. Then, each whale's surfacing and dive rates, and length of surfacings and divea are presented.

Gray whale migration rates measured from 0600-1700 were considered as daytime data, and were compared with nighttime migration data obtained from

1700-0600. The gray whales' typical swimming pattern while migrating is composed of a series of surfacing, usually accompanied by respirations or "blows", separated by short shallow dives. Together these surfacings and shallow dives constitute a "surfacing interval". Each surfacing sequence is followed by a long deep dive. In the following analysis, the rate of surfacing referred *to* the number of times that a whale surfaced during all of its surface sequences within a given hour. Surfacings were analyzed as the rate of surfacing per hour and the duration of each surfacing in seconds. The short dives between blows were not analyzed for each whale; however, the mean length of these short dives for all whales was 27.00 * SD 14.13 sec (n= 2302) . Only long deep dives, those greater than one minute, were analyzed as the rate of dives per hour and duration in minutes.

Whale No. M-1: The first gray whale was rsdio-tagged at 1255 on January 6, approximately 2.8 nm northwest of Point Sur (36°16.4'N, 121°58.6'W). This whale was swimming south with three other whales and wss" tracked by both the vessel and the shore teams until 1850 when its signal was lost and never recovered. The whale 's last known position was approximately 13.5 nm southeast of Point Sur (36"08. 7 ' N, 121"42.0' W).

Whale M-1 was tracked a total of 12.54 nm during 4.33 hr of daylight at a swimming rate of 2.89 kts (5.35 km/hr), and a total of 5.77 nm during 1.58 hr of nighttime at a rate of 3.65 kts (6,76 km/hr) (Table 1).

Its rate of surfacing increased from 44. 3/hr to 47 .4/hr during the two daylight houra of tracking (1401-1558), but then declined to 32.2/hr during the last hour before the signal from the whale was lost (1700-1759) (Fig. 5A). The mean length of surfacing for this whale increased throughout the tracking period from 1.3 ± SD 0.4 sec to 1.5 ± SD 0.4 sec (Fig. 5B). This whale's rate of dives greater than 1 min decreased from a high of 28.9/hr from 1500 to 1559 to 23.2/hr from 1700 to 1759 (Fig. 5C). The mean length of dives was variable and increased from 1.6 ± SD 0.45 min to 2.4 ± SD 2.2 min during the tracking period (Fig. 5D).

Whale M-2: One whale in a group of 7 animals was tagged at 14:45 on January 8 approximately 4.5 nm southwest of Point Lobos (36°27.5'N, 121059.0' W). This group was trscked by both the vessel and the shore teams until 09:00 the following morning when the whales reached the southern end of the study area at Piedras Blancas (35°40.2'N, 121°22.2'W).

Whale M-2 was tracked for 7.75 nm during 2.80 hr of daylight at a swimming rate of "2.77 kts (5.13 km/hr) the afternoon it was tagged, and for an additional 7.24 nm during 2.47 hr of daylight at a rate of 2.94 kts (5 .44 km/hr) the following morning. During the night this whale traveled 45.56 nm in 12.98 hrs at a rate of 3.51 kts (6.50 km/hr), slightly faster than its daytime swimming rate (Table 1) .

This whale's rate of surfacing reached its maximum just at sunset (1700) at 79 .5/hr and rhen declined throughout the night to a low of 33. 0/hr from 0300-0359 (Fig. 6A). The mean length of surfacings varied throughout the day and night ranging from 2,1 ± SD 0.4 sec from 2000-2059 to 2.7 ± SD 0,5 sec from 2300-2359 (Fig. 6B). This whale' a rate of long dives reached its peak of 21/hr from '1900-1959 and the lowest dive rate of 8/hr at 0000-0059 (Fig. 6C). The mean length of long dives for this whale ranged from 2.1 ± SD 0.8 min during the period 1900-1959 to 6.0 ± SD 1.2 min from 0000-0059 (Fig. 6D).

Table 1. Summary of day and night migration rates for nine gray whales that were radio-t agged during their southward migration along the central California coast in 1986.

WHALE NO.	DATE	DAY N. MILES	DAY HRS	DAY RATE KTS	NIGHT N. MILES	NIGHT HRS	NIGHT RATE KTS
M-1	06 JAN	12.54	4.33	2.89*	,5.77	1.58	3.65*
M-2	08 JAN PM 09 JAN AM	7.75 7.24	2.80 2.47	2.77* 2 .94*	45.56	12.98	3.51*
M-3	10 JAN	6.77	1.58	4. 27*	49.11	13.50	3. 64*
M-4	11 JAN	———	———	———	33.94	13.25	2.56
M-5	11 JAN	———	———	———	34.27	13.25	2.59
M-6	12 JAN PM 13 JAN AM	5.94 10.89	2.00 2.58	2.97** 4.21**	44.39	12.92	3 .44*
M-7	12 JAN PM 13 JAN AM	4.77 11.08	2.50 3.27	1 .91* 3.39-	40.68	13.50	3.01**
M-8	17 JAN	19.96	5.58	3.57	35.73	9.50	3.76
M-9	17 JAN	3.93	1.00	3.93	46.91	12.00	3.91
			DAY $\bar{X}$ =	3.23		NIGHT $\bar{X}$ =	3.34

* = Tracked by combination of vessel and shore team
** = Tracked by vessel alone.
No * = tracked by shore team alone.
N. Miles = Nautical Miles.

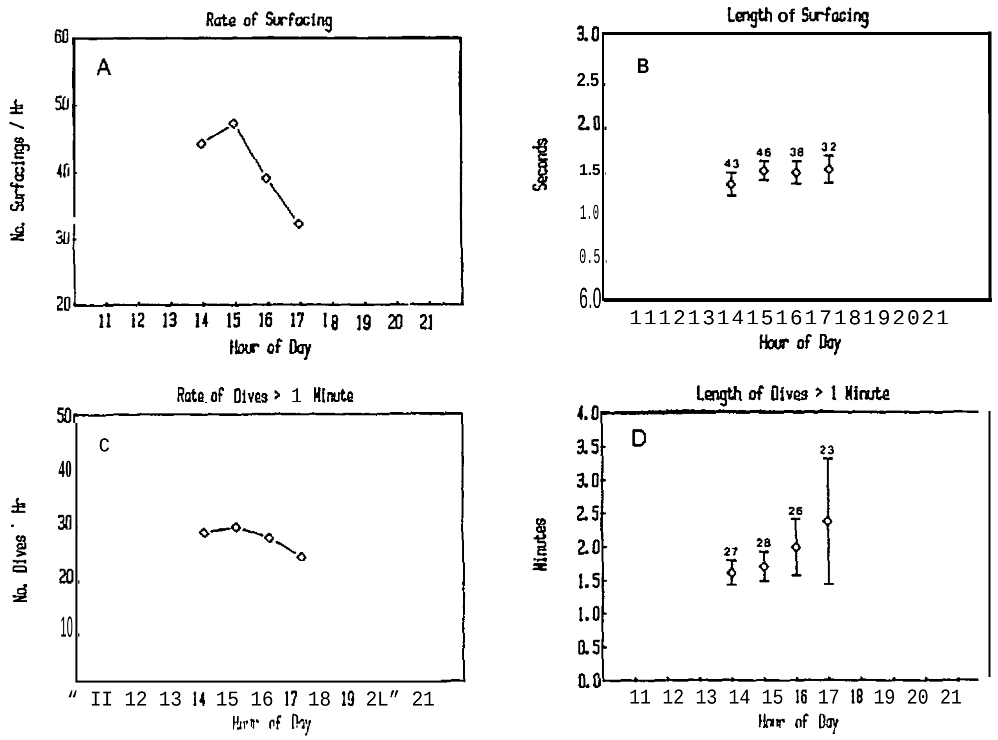


Figure 5. Whale M-1's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are mesns, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

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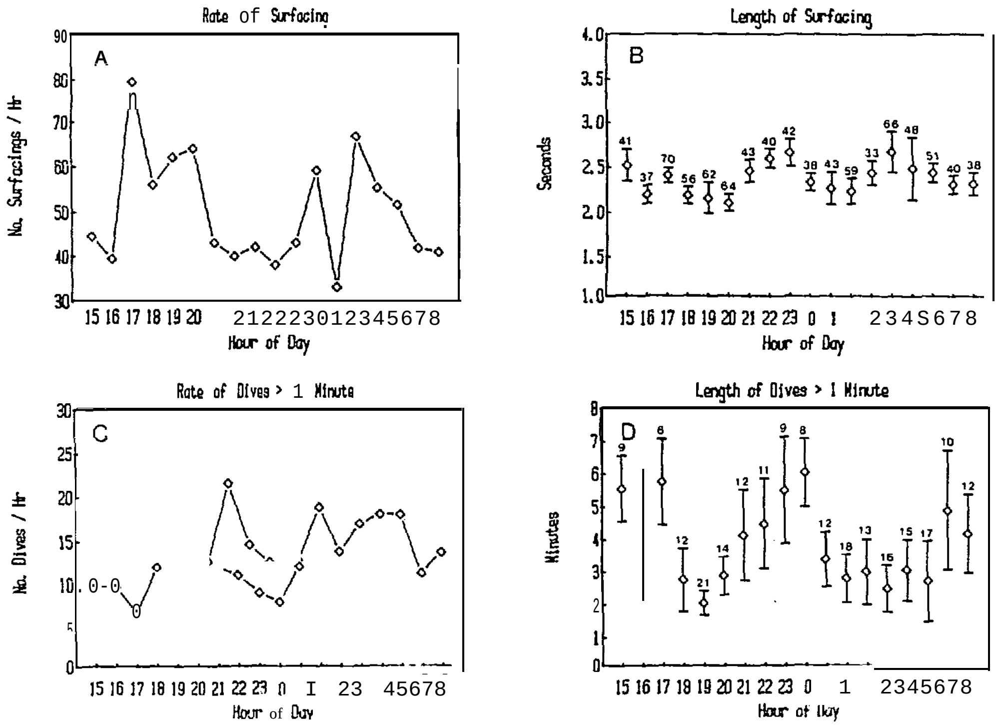

Figure 6. Whale M-2's rates of surfacing (A). mean lengths of surfacings (If), rate of dives greater than 1 min (C), and mean' lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D sre means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizea.

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Whale M-3: The third whale was traveling by itself, and was radio-tagged at 1555 on January 10 approximately 2.5 nm west of Carmel Bay (36°32.1' N, 121°58.2' W). This whale was tracked by the vessel until 2300 when the shore team took over the tracking and followed the animal until 0700 the following morning when it reached the southern end of the study area (35°49.0' N, 121°24.0' W).

Overall whale M-3 was tracked during 1.58 hr of daylight over 6.77 nm at a rate of 4.27 kts (7.91 km/hr), and during 13.50 hr of nighttime travel over 49.11 nm at a rate of 3.64 kts (6.74 km/hr) (Table 1).

The surfacing rate of whale M-3 was variable throughout the tracking, reaching maximums of 84.0/hr at 1600-1659, 83.5/hr at 2300-2359, and 80.6/hr at 0200-0259. The lowest surfacing rates were 39.8/hr and were obtained from 0000-0059 (Fig. 7A). The mean length of each surfacing was also variable and ranged from a low of 1.4 ± SD 0.6 sec at 1900-1959 to a high of 2.8 ± SD 0.5 sec just after sunrise from 0600-0659 (Fig. 7B). This whale's rate of long dives increased after it was tagged from 10.7/hr to a peak of 28.9/hr just before midnight (2300-2359), afterwhich its rate declined during most of the early morning to around 11.9/hr. This whale began to dive more frequently just before sunrise and at the end of the tracking its dive rate was 21.4/hr (Fig. 7C). Its mean length of dives was extremely variable and ranged from 1.1 ± SD 0.7 sec to 3.0 ± SD 1.6 sec (Fig. 7D).

Whale M-4: Whale M-4 was one of two whales in a group of 6 that was tagged at 17:00 on January 11 approximately 2.5 nm northwest of Point Sur (36°19.7'N, 121°57.6'W). This whale was tracked by the shore team from 1715 to 0630 the following morning when it was about 17 nm north of Point Piedras Blancas (35°55.0' N, 121°57.6' W). The shore team was unable to determine whether the whale had remained with its group during the night; however, the signals from whale M-5, who was one of the group members that included whale M-4, were received during the same time periods and from the same directions as those of M-4.

This whale traveled 33.94 nm in 13.25 hr for a nighttime swimming rate of 2.56 kts (4.74 km/hr) (Table 1).

M-4's rate of surfacing was greatest at 50.0/hr immediately after it was tagged, and declined to a low of 18.1/hr from 2300-2359 (Fig. 8A). Its mean length of surfacing varied from a low of 1.2 ± SD 0.5 sec from 2000-2059 to 4.3 ± SD 1.3 sec from 2300-2359 (Fig. 8B). The whale's rate of long dives increased from 5.5/hr when it was tagged to 21.2/hr from 0100-0159, afterwhich it declined and increased again at sunrise to 21.1/hr (Fig. 8C). The mean length of M-4's dives was variable ranging from a low of 2.7 ± SD 1.8 min from 0000-0059 to a high of 7.8 for a single long dive approximately 30 min after it was tagged (1735-1743) (Fig. 8D).

Whale M-5: This was the second whale to be tagged in the group of 6 that included whale M-4 when they were approximately 2.5 nm northwest of Point Sur (36°19.7'N, 121°57.6'W). The shore team monitored this whale's movements from 1715 on January 11 until sunrise at about 0630 on the morning of January 12 when it was approximately 17 nm north of Point Piedras Blancas (35°54.5'N, 121°29.5'W). Whale M-5 traveled 34.27 nm

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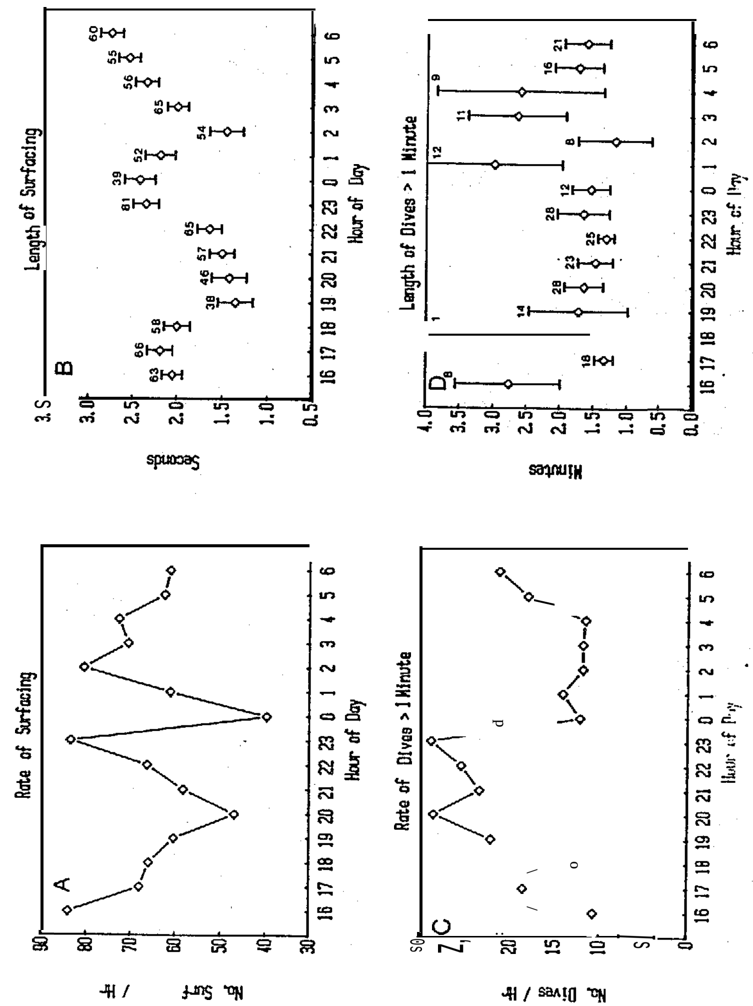

Figure 7. Whale M-3's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

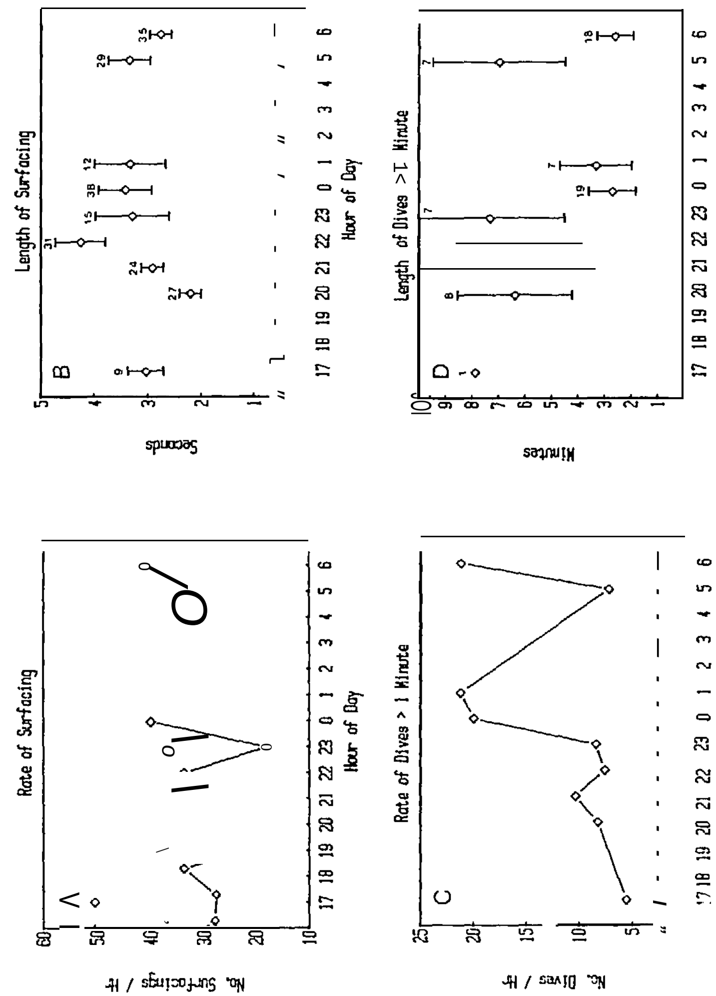

Figure 8. Whale M-4's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

during 13.25 hr at a swimming rate of 2.59 kts (4.80 km/hr) (Table 1). Although the shore observers did not obtain visual confirmation of whale M-5 swimming with whale M-4, the signals from their radio-tags were received at the same locations and during the same time periods, suggesting that the whales were continuing to migrate together.

Whale M-5's rate of surfacing increased from a low of 21.6/hr immediately after it was tagged to a high of 35.6/hr from 2200–2259, after which its rated declined to 17.35/hr from 0300–0359, and finally reached its highest rate of 45.3/hr just before sunrise from 0500–0559 (Fig. 9A). This whale's mean length of surfacing ranged from a low of 0.80 ± SD 0.32 sec from 0200–0259 to 1.78 ± SD 0.42 sec just before sunrise from 0500–0559 (Fig. 9B). Its rate of long dives increased slowly from 7.2/hr immediately after it was tagged to 12.2/hr at sunrise (Fig. 9C). M-5's mean length of dive was highly variable throughout the tracking, ranging from 4.55 ± SD 1.98 min to 8.64 ± SD 1.01 min. (Fig. 9D)

<u>Whale M-6</u>: This whale was migrating in a group of 4 animals when it was tagged about 2.5 nm southwest of Point Lobos (36°30.2'N, 121°58.4'W) at 1430 on January 12. The radio-tag struck the whale low on the back and attached approximately 2-2.5 ft below the dorsal mid-line. Because of its low position, the tag transmitted an audible signal only when the whale exaggerated its roll at the surface. Therefore, attempts to track this animal were abandoned at 1500. However, its signal was re-encountered at 17:00 while the vessel was tracking whale M-7. Thus, the migration record for whale M-6 began at 1430 and continued until 0946 the following morning when it was about 2 nm north of Point Piedras Blancas (35°42.1'N, 121°12.2'W). In total this whale traveled 56.5 nm during 19.26 hrs.

During the first 2.5 hr of daytime tracking whale M-6 traveled 4.77 nm during 2.50 hr at a swimming rate of 1.91 kts (3.54 km/hr). During the subsequent 13.50 hrs of night migration the whale traveled 40.68 nm at a rate of 3.01 kts (5.57 km/hr). Following sunrise the whale traveled another 11.08 nm during 3.27 hr at a rate of 3.39 kts (6.28 km/hr) (Table 1).

Accurate records of M-6's surfacing and dives were not obtained until 0242 on the morning of January 13, when its surfacing rate was highest at 65/hr. Afterward this rate declined to 28.4/hr from 0300–0359, increased to 56/hr from 0544–0559, and then declined to 24.36/hr following sunrise from 0700–0749 (Fig. 10A). M-6's mean length of surfacing was variable declining from a mean of 3.38 ± SD 1.19 sec from 0242–0254 to 2.57 ± SD 1.26 sec from 0700–0747 (Fig. 10B). This whale's dive rate was lowest at 8.00/hr from 0544–0559, but increased dramatically at sunrise to its maximum of 22.10/hr from 0600–0657 (Fig. 10C). The whale's mean length of dives was variable ranging from 2.15 ± SD 1.35 min from 0600–0657 to 5.19 ± SD 3.43 min from 0306–0359 (Fig. 10D).

<u>Whale M-7</u>: This whale was one of a group of 5-7 whales that was tagged at 1530, approximately one hour after whale M-6 when they were 2.0 nm west of Carmel Bay (36°32.3'N, 121°58.4'W) on January 12.

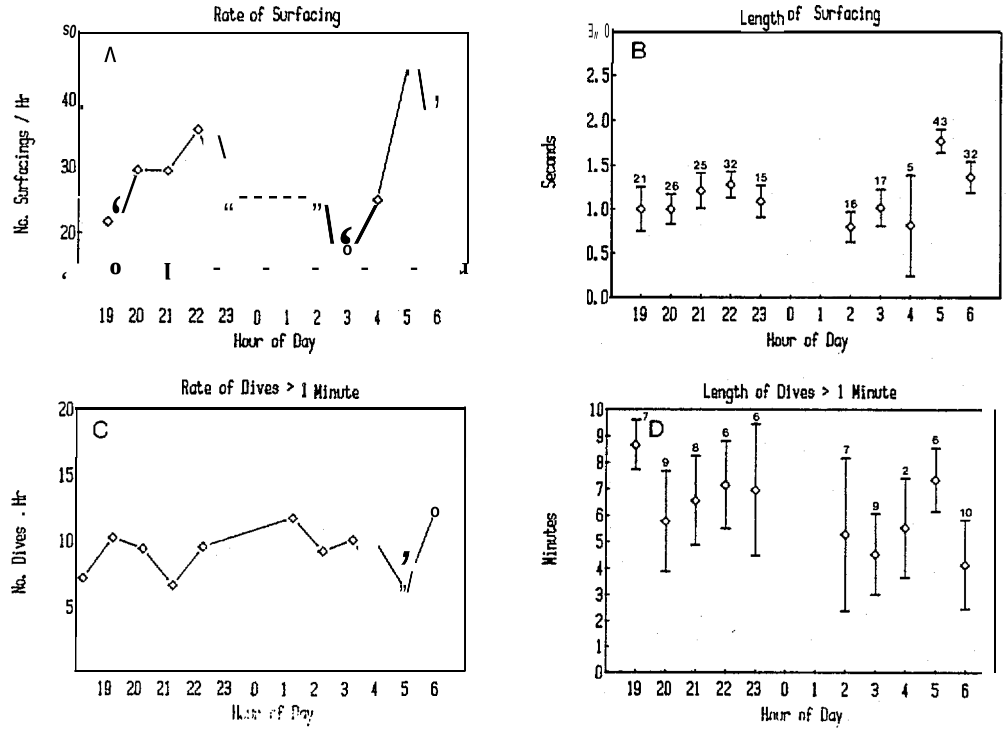

Figure 9. Whale M-5's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

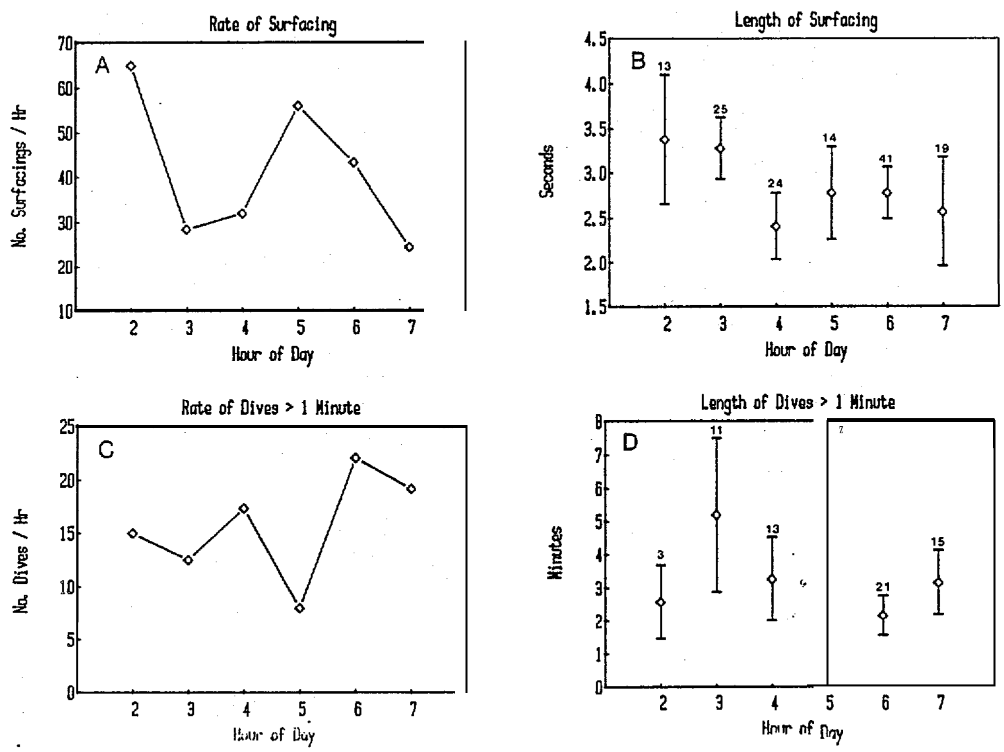

Figure 10. Whale M-6's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

Whale M-7 traveled 5.95 nm during 2.00 hr at a rate of 2.97 kts (5.50 km/hr) before sundown. During the night it migrated 44.39 nm during 12.92 hrs at 3.44 kts (6.37 km/hr). The following morning this whales was tracked for an additional 10.89 nm during 2.58 hrs at a rate 4.21 kts (7.80 km/hr) (Table 1).

Whale M-7's rate of surfacing was greatest at 60.0/hr immediately after it was tagged, but then it declined to a low of 26.9/hr from 0100-0159 in the morning. This whale's surfacing rate increased again at 0300 to 41.8/hr and then declined again to 35.4/hr at the end of the tracking session (Fig. 11A). M-7's length of surfacing gradually increased from a low of 2.18 ± SD 0.45 sec from 1800-1859 to 3.29 ± SD 0.49 sec at 0702-0759 just after sunrise (Fig. 11B). The rate of dives was lowest at 10.3/hr from 1706-1758 and greatest at 23.7/hr from 2301-2359 (Fig. 11C). M-7's mean length of dives was variable and ranged from a low of 2.38 ± SD 1.14 min from 2301-2359 to a high of 4.81 ± SD 1.63 min from 0702-0759 just after sunrise (Fig. 11D).

Whale M-8: Was a lone animal that was within 0.25 nm of a group of 6-7 whales when it was tagged at 1153 on January 17 approximately 2.5 nm south of Point Piños (36°36.4'N, 121°59.0'W). Within 30 min this whale had joined three others and the four whales migrated together throughout the daylight period of tracking. This whale was tracked by the shore team until its signal was lost at 0300 approximately 12 nm north of Point Piedras Blancas (35°50.0'N, 121°26.9'W).

During the day whale M-8 traveled 19.96 nm during 5.58 hr at a swimming rate of 3.57 kts (6.61 km/hr). During 9.5 hr of nighttime travel the whale traveled 35.73 nm at a rate of 3.76 kts (6.96 km/hr) (Table 1).

Whale M-8's surfacing rate declined to its lowest rate of 23.2/hr one hour after it was tagged, but then increased to its maximum value of 55.6/hr from 2232-2243. Its rate of surfacing was 28.5/hr during the last hour of tracking before its signal was lost (Fig. 12A). This whale's mean length of surfacing was variable and ranged from 1.68 ± SD 0.53 sec from 1300-1359 to 2.36 ± SD 0.90 sec during the first hour after it was tagged (Fig. 12B). The rate of long dives for M-8 increased throughout the tracking from a low of 10.9/hr from 1400-1459 to a high of 33.3/hr from 0014-0024 (Fig. 12C). The mean length of dives for this whale was greatest during the first 3 hr of tracking when it ranged from 3.81 ± SD 2.05 min to 4.09 ± SD 2.77 min (1216-1444), afterward the mean dive length declined and was 2.43 ± SD 2.07 min from 0300-0359 (Fig. 12D).

Whale M-9: Whale M-9 was swimming with two other animals approximately 4.5 nm north of Point Sur (36°22.9'N, 121°56.1'W) when it was tagged at 1430 on January 17. This whale was tracked by the shore team until it reached the southern end of the study area at 0530 on January 18 approximately 1.5 nm north of Point Piedras Blancas (35°42.0'N, 121°21.0'W).

M-9 traveled 3.93 nm during the one hour of daylight tracking at a rate of 3.93 kts (7.28 km/hr). After dark, this whale traveled 46.91 nm during 12.00 hr at an average rate of 3.91 kts (7.24 km/hr) (Table 1).

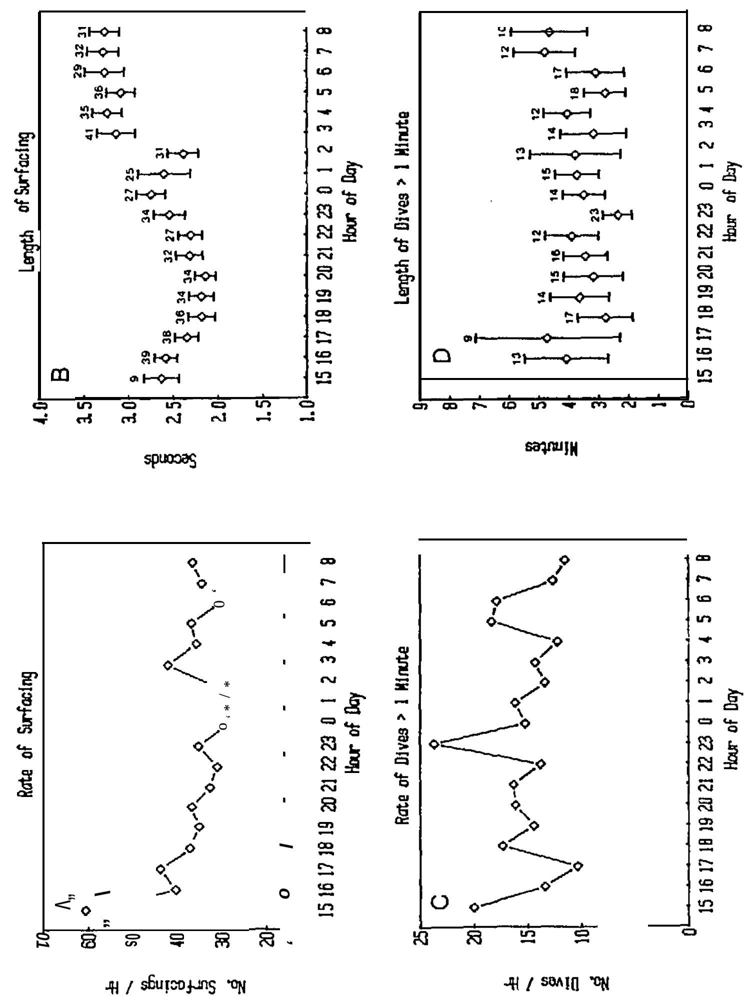

Figure 11. Whale M-7's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

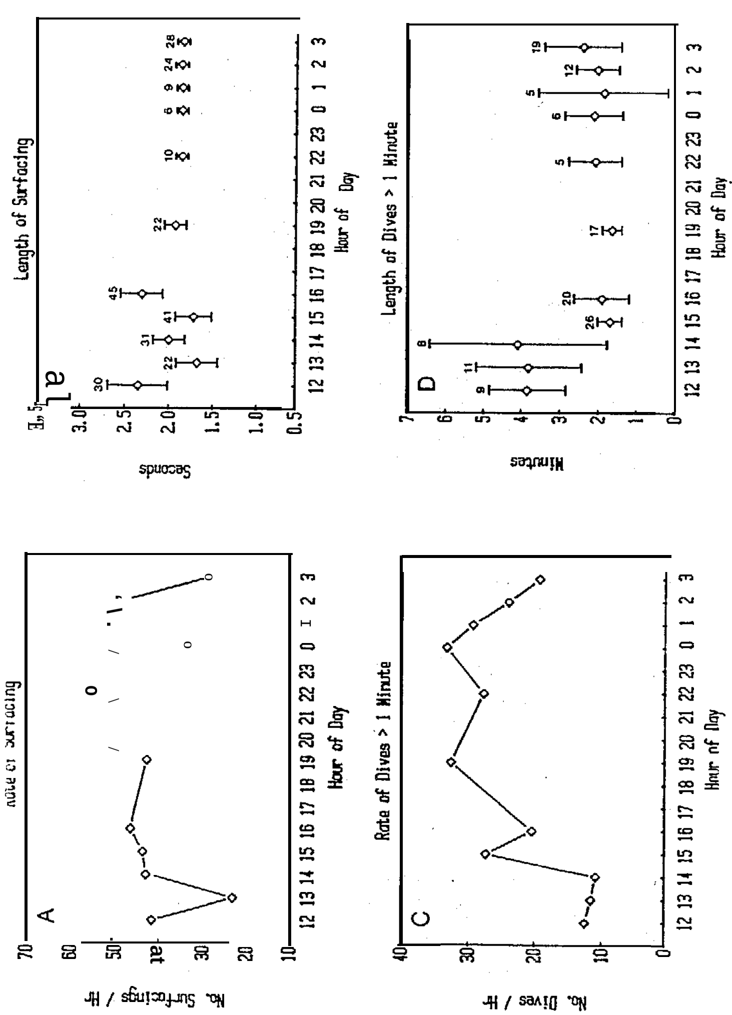

Figure 12. Whale M-8's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

This whale's rate of surfacing was greatest at 55.6/hr just after it was tagged (1640-1659), but declined gradually throughout the evening to 30.9/hr from 0101-0159. Its surfacing rate then increased during the early morning hours to 40.0/hr just before daybreak (0506-0533) (Fig. 13A). M-9's mean length of surfacing increased gradually throughout the night from 2.16 ± SD 0.44 sec when it was tagged to 2.79 ± SD 0.62 sec from 0300-0356, afterwhich its mean surface time declined to 2.13 ± SD 0.68 sec at the end of the tracking (Fig. 13B). This whale's rate of long dives was relatively consistent, but declined throughout the night from 22.2/hr immediately after it was tagged to a low of 10.8/hr from 0401-0423 (Fig. 13C). Finally, its mean dive length generally increased during the period of tracking from 1.86 ± SD 0.61 min to a high 5.40 ± SD 1.17 min from 0401-0423 (Fig. 13D).

Day and Night Migration Rates

The net rate of daytime travel for the nine radio-tagged whales ranged from 1.91 to 4.27 kts (3.54 to 7.91 km/hr) with a mean rate of 3.23 ± SD 0.70 kts (5.98 km/hr) and a 95% C.I. of 2.73-3.73 kts (5.05-6.91 km/hr). The daytime migration rate of whale M-3, M-6's morning rate, and M-7's daytime rate were all outside the confidence interval for all the daytime rates. During the night, the migration rates ranged from 2.56 to 3.91 kts (4.74 to 7.24 km/hr) with a mean rate of 3.34 ± SD 0.50 kts (6.18 km/hr) and a 95% C.I. of 2.96-3.73 kts (5.48-6.91 km/hr). The nighttime migration rates of whales M-4, M-5, M-8 and M-9 were outside the confidence interval for all nighttime rates. When compared as two groups, the day and night migration rates were not significantly different (t_s= 0.389, P > 0.50), and when pooled gave an overall mean migration rate of 3.31 ± SD 0.62 kts (6.13 km/hr) with a 95% C.I. of 3.01-3.61 kts (5.57-6.68 km/hr).

Because of the possibility that the vessel may have an influence on the migration rates of the whales that it followed, migration rates determined from the vessel alone (six cases) were compared with rates based on the shore team tracking alone (six cases), and with rates determined from a combination of the vessel and shore team tracking efforts (seven cases). The ANOVA for these three samples of migration rates indicated that the means of these three samples were not significantly different (F= 0.2579, P = 0.77).

Overall Surfacing and Dive Lengths

The radio-tagged whales provided precise measures of the amount of time that migrating whales spend at the surface and below the water. This information may be useful in determining the sightability of whales during census surveys, which is necessary to calculate correction factors for whales missed by observers because they are below the surface (Eberhardt et al., 1979; Jones and Swartz, 1986).

The frequency distributions for the lengths of 3,617 pairs of surfacings and dives from all nine radio-tagged whales are shown in Figure 14A-B. The overall mean length of a surfacing was 2.25 ± SD 0.83 sec, with a range of 0.37-9.26 sec, and a 95% C.I. of 2.22-2.26 sec. There was a distinct break in the distribution of dives beginning with

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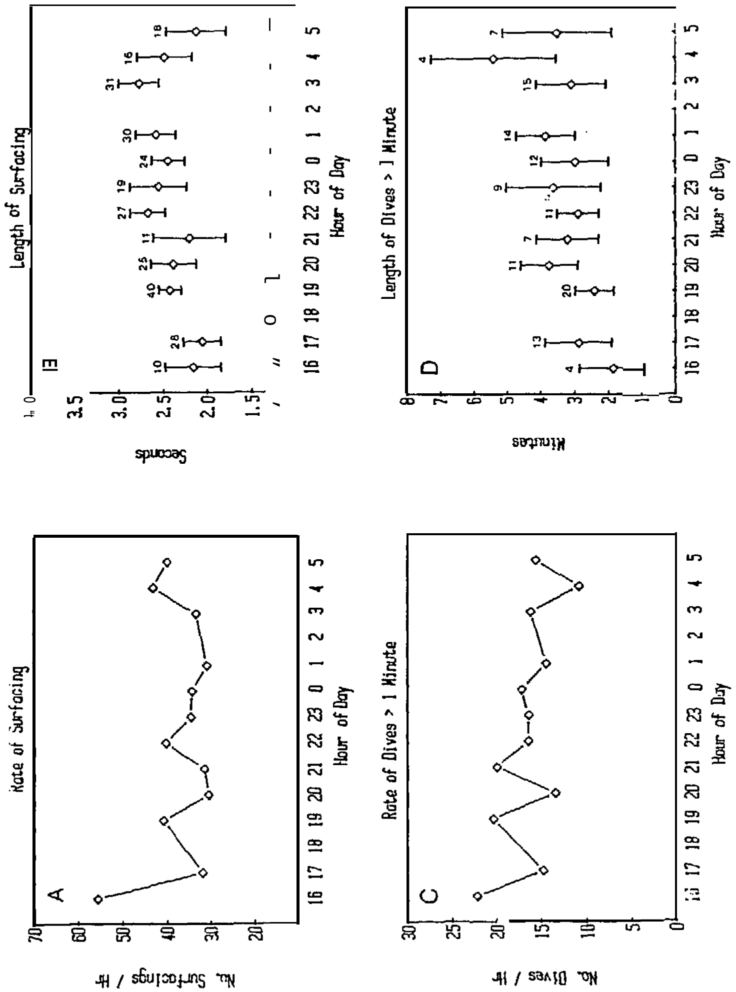

Figure 13. Whale M-9's rates of surfacing (A), mean lengths of surfacings (B), rate of dives greater than 1 min (C), and mean lengths of dives greater than 1 min (D), for each hour that it was tracked. Symbols in B and D are means, vertical bars are 95% confidence limits to the means, and numbers at the top of each bar are sample sizes.

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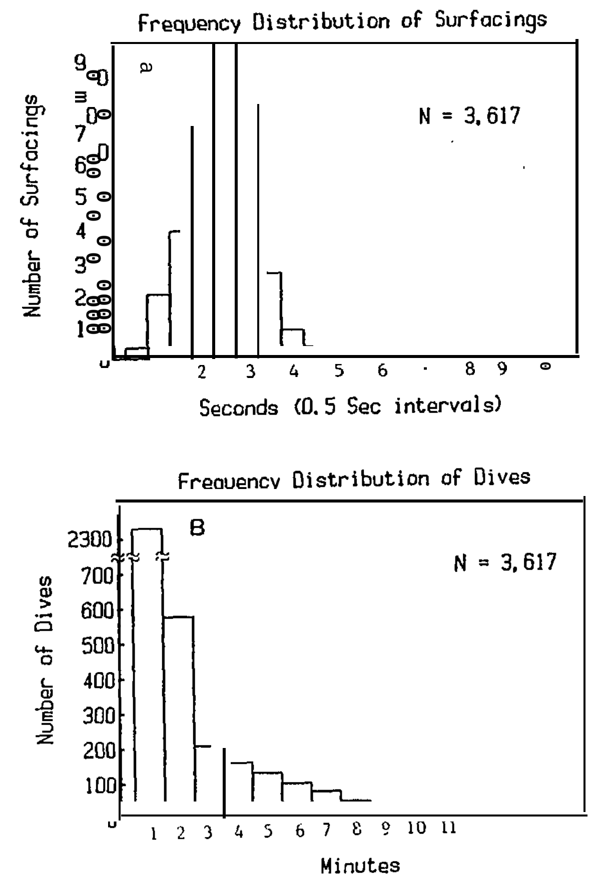

Figure 14. The frequency distribution of lengths of surfacings (A) and lengths of dives (B) for all nine gray whales radio-tagged and tracked along central California.

dives ≥ 1 min. Shallow dives of < 1 min usually occur in-between surfacings or blows by the whale, and differ from longer deep dives that occur between entire surfacing intervals. Short dives of < 1 min comprised 64% of all dives. The mean length of the short dives between blows was 27.00 ± SD 14.13 sec (n=2,302), with a range of 0.27-59.97 sec, and a 95% C. 1. of 26 .42-27 .58 sec. The mean length of long dives (≥ 1 rein) was 3.10 ± SD 2.10 min. with a range of 1.00-13.08 min, and a 95% C.I. of 2.99-3.22 min.

The length of an average surfacing interval (all surfacings and short dives between blows during a respiration cycle) may be calculated from the mean lengths of surfacings and short shallow dives, and from these, the average percent of time that a migrating whale spends at the surface may be determined. The average surfacing interval is defined as the mean length of a surfacing (2.25 see) plus the mean length of the short shallow dive (27.00 see), multiplied by the mean number of surfacings during a surfacing interval (2.75), or 80.43 sec. An entire surfacing-dive cycle would be the average surface interval (1.34 min) plus the mean length of a long deep dive (3.10 rein), or 4.44 min. Therefore, a migrating whale would be expected to surface to breathe once every 4.44 rein, and spends an about 70% of its time below the surface during deep dives.

DISCUSSION

Migration Rates

Mste and Harvey (1984), used external tags to radio-tag 14 gray whales in Bsja's San Ignacio Lagoon in 1979 and 1980, and report thst these whales are excellent subjects for the attachment of radio tags; they suggest that because gray whales tolerate large numbers of ecto-parasites and epizoites, they may be sdapted to foreign objects in the skin.

On the other hand, Harvey and Mste (1984) also state that gray whales have been less than ideal animals for the radio-tagging studies because of their habit of rubbing against the seafloor during feeding and against each other while courting, mating, and raising calves, which increases the chance of dislodging an attached tag. The radio-tagging efforts with gray whalea prior to 1986, however, have involved the use of external radio transmitters. These studies, reviewed by Mate and Harvey (1984), employed a variety of methods which included flexible harness bands attached around the belly of restrained calves (Norris snd Gentry, 1974) , a tag surgically sutured to a captive yearling (Evans, 1974b; Sweeney and Mattsson, 1974) , and the first successful radio-tagging of unrestrained gray whales with umbrella and barnacle tags (Mate et al., 1983). The problem of short tag retention was minimized in this study by the use of the small sub-dermal capsule tag that incorporated small size, minimal penetration depth and tissue trauma, long attachment duration, and eaae of deployment on free swimming whales.

Although slightly slower than previously published swimming speeds, the mean daytime swimming speed of 3.23 kts (5 .98 km/hr) determined from whales radio-tagged during this study compares closely with rates of

southward migration from earlier studies. Published estimates of gray whale daytime swimming speeds during southbound migration were reviewed by Malme et al. (1984) and ranged from 3.2 kts (5.9 km/hr) (Rugh and Braham, 1979) to 5.5 kts (10.2 km/hr) (Cummings et al., 1968), with an overall mean rate of 4.4 kts (8.1 km/hr) (Table 2). Concurrent with this 1986 study, a daytime migration rate of 3.44 ± SD 1.34 kts (6.37 km/hr) was determined by the National Marine Mammal Laboratory's shore census team during the 1985/1986 shore census at Granite Canyon (Rugh et al., 1986) . This swimming rate was not significantly different from the daytime migration rate for the whales radio-tagged in 1986 (ts= 0.284, P > 0. 75), or the overall mean migration rate for the Monterey whales of 3.31 ± SD 0.62 kts (6.13 km/hr) (ts= 0.203, P > 0.75).

Previously there has been little evidence to support the idea that day and night migration rates were the same (Reilly, 1981; Reilly et al., 1980) . Rugh (1984) collected night migration data using night-vision optical equipment of southbound migrating whales at Unimak Pass, Alaska. The results of his two experiments differed; one experiment suggested that there waa no diurnal fluctuation in the rate of migration past the census site, while the second experiment suggested that the whales slowed to 73% of their day rate. Gilmore (reported in Reilly, 1984) felt that gray whales slowed their swimming speed at night in response to limited visual cues for orientation. Other investigators also believed that gray whales slowed their migration rates at night (Hubbs and Hubbs, 1967; Rsmsey, 1968), but they presented only indirect evidence.

Evidence supporting the uniformity of day and night swimming speeds comes from a 1985 pilot study by Swartz and Harvey (1985) that radio-tagged two gray whales during the 1984/1985 southward migration, and tracked them along the ssme portion of the migration route as in the 1986 study. The first whale traveled at 3.71 kts (6.87 km/hr) during the day, and this was not significantly different from the 1986 overall daytime rate (ts= 0.651, P > 0.70). Its night time rate waa 3.38 kts (6.25 km/hr), again was not significantly different from the 1986 overall night time rate (t_S= 0.007, P > 0.95). The second whale traveled at 3.45 kts (6.39 km/hr) during the day, and 3.72 kta (6.89 km/hr) during the night, neither of which were significantly different from the 1986 overall night time rate (t_S=0.298 P >0.70 snd t_S= 0.718, P > 0.45 respectively).

Immediately after this study in central Calif ornia, an additional nine gray whales were tagged and radio tracked aa they migrated through the Channel Islands National Marine Sanctuary (CINMS) (Jones and Swartz, 1986) . The daytime migration rstes of the CINMS whales ranged from 2.11 to 3.65 kts (3.91-6.76 km/hr) with a mean of 3.02 ± SD 0.44 kta (5.59 km/hr) and a 95% C. I. of 2.68-3.36 kta (4.96-6.22 km/hr). Doring the night, their net migration rate ranged from. 2.99 to 4.18 kts (5.54 to 7.74 km/hr) with a mean rate of 3.45 ± SD 0.45 kts (6.38 km/hr) and a 95% C.I. of 2.97-3.92 kts (5,50-7.26 km/hr). The day and night migration rates of the CINMS whales were not significantly different from the rates measured off central California (t_S= 0.773, P > 0.40 and t_S= 0.434, P > 0.70 respectively). The day and night migration rates for the CINMS whales were not significantly different (t_S= 1.821, P > 0.91), and when pooled gave an overall mean migration rate of 3.19 ± SD 0.48 kts (5.91 km/hr) and a 95% C.I. of 2.92-3.45 kta

Table 2. Gray whale southward migration rates. Adapted from Malme et al. (1984).

Location		Migration Rate Kts	Km/hr	Reference
CA/Oregon/B.C. Coasts		4.00	7.41	Pike, 1962
Yaquina Head to Monterey		3-4	5.56-7.41	Herzing and Mate, 1984
Monterey		4.05	7.50	Malme et al., 1983
Monterey		4-5	7.41-9.26	Rice and Wolman, 1971
Monterey to San Diego		4.7	8.70	Reilly, 1981
San Diego (Point Loma)		4.6	8.52	Pike, 1962
San Diego		5.5	10.19	Cummings et al., 1968
San Diego (Point Loma)		3.9	7.22	Sumich, 1983
San Diego		4.6	8.52	Wyrick, 1954
Unimak Pass to San Diego		2.3	4.26	Rugh and Braham, 1979
Monterey		3.34	6.19	Breiwick and Dahlheim, 1986
Monterey	day:	3.58	6.63	Swartz and Harvey, 1985
	night:	3.55	6.57	
Channel Islands:	day:	3.02	5.59	Jones and Swartz, 1986
	night:	3.45	6.39	
Monterey	day:	3.23	5.98	This Study
	night:	3.34	6.19	

[5.41-6.39 km/hr). This mean migration rate for the CINMS whales waa not significantly different from the mean rate of 3.31 kts (6.13 km/hr) for whales tracked along the central California coast (t_s= 0.625, P > 0.50).

The nighttime migratory behavior of the gray whales radio-tagged during this study was essentially the same as that observed during the day, and the mean net rate of nighttime swimming of 3.34 kts (6.18 km/hr) was only slightly faster than the mean daytime rate. Notably, there was no significant difference between day and night time migration rates as determined from this study, indicating that the census estimates baaed on daytime shore counts at Granite Canyon need not be corrected for diel changes in migration rate. The uae of short-term VHF radio-tags in this study demonstrates that these remote telemetric devices are a useful and cost effective tool for the study of gray whale migration rates, and their surfacing and diving behavior over 24-hr perioda.

Correction Factors for Aerial Surveys

Quantitative estimates of the percent of time that migrating whales spend at and below the surface are extremely important in formulating correction factors to estimate relative abundance of cetaceans from raw counts from aerial surveys. Radio-tags provide precise measures of the amount of time that migrating whales spend at the surface, and by coupling these data with behavioral observations from a survey aircraft, the proportion of time that a whale would be visible to an observer may be estimated.

Raw transect counts may be biased toward underestimating the actual number of whales in an area. Compensation for this bias requires the calculation of two correction factors for the estimation of whale abundance from strip surveya: (1) to correct for whales missed because they were submerged and thus invisible, and (2) to correct for whales that were on the surface but miseed by the observera (Eberhardt et al., 1979). The first source of bias is a function of the length of time the observer has to view the survey araa, and the whale 'a surface interval and duration of dives. A correction factor to determine the probability that a whale will surface while the ohserver is viewing the survey area is given by Eberhardt et al. (1979) as

$$P = (s + t) / (s + u) \qquad (1)$$

where s is the mean duration of a surface interval (defined here aa the length of time that a whale is at the surface between long dives), u is the mean duration of dives (defined here aa long dives other than short dives between blows), and t is the length of time a point along the transect line is visible to the observer. Raw counts should be divided by P to correct for submerged whales.

A correction factor to compensate for submerged whales may be derived from 130.59 hra of radio-telemetry data for surfacings and dives of nine whales tagged during this stud y (see Table 1). Generally the respiration cycle of grays consists of a sequence of surfacings (when the whale blows), separated by short shallow dives. and followed by a long deep dive. Here, the surface interval was defined as a series of short surfacings separated by short dives; hence, the mean duration of the surface interval (a) may be defined as the mean length of a surfacing (2.25 ± SD 0.83 see, n = 3,617) plus the mean length of the short dive between surfacings (27.00 ± SD 14.132 see, n = 2,302) multiplied by the mean number of surfacings during a respiration cycle (1 .57 = no. surfacings / no. long dives), or:

$$s = (2.25 \text{ aec} + 27.00 \text{ aec})\ (1.57) = 45.92 \text{ sec}. \qquad (2)$$

The mean duration of long dives (u) was 186.00 ± SD 126.00 sec (n = 1.315). The time (t) that a point along the transect line would be visible to an observer flying at a standard survey altitude of 1,500 ft (457 m) and 90 kta (167 km/hr) is approximately 37 sec (Jones and Swsrtz, 1986). Thus, a value for P may be estimated as:

$$P = (45.92 \text{ sec} + 37.00 \text{ see})/(45.92 \text{ sec} + 186.00 \text{ see}) = 0.357. \qquad (3)$$

Therefore, raw counts from surveys along this portion of the central California Coast should be divided by P = 0.357 to correct far whales missed because they were below the surf ace. A similar procedure waa used to calculate a correction factor for whales surveyed in the Channel Islands National Marine Sanctuary from nine radio-tagged whales. The value for P in this area was 0.398 (Jones and Swartz, 1986), suggesting that the whales surfacing-dive behavior was slightly different while passing through the northern Channel Islands.

The second source of bias, whales at the surface but missed by the observer, ia a function of environmental conditions affecting visibility during the survey and the observer's sighting ability and experience (Leatherwood et al., 1978; Davis et al., 1982). Correction fOr this bias requires that simultaneous observations from two independent observera be compared to determine the ratio Of whales seen by both observera to the number seen by each observer alone.

ACKNOWLEDGMENTS

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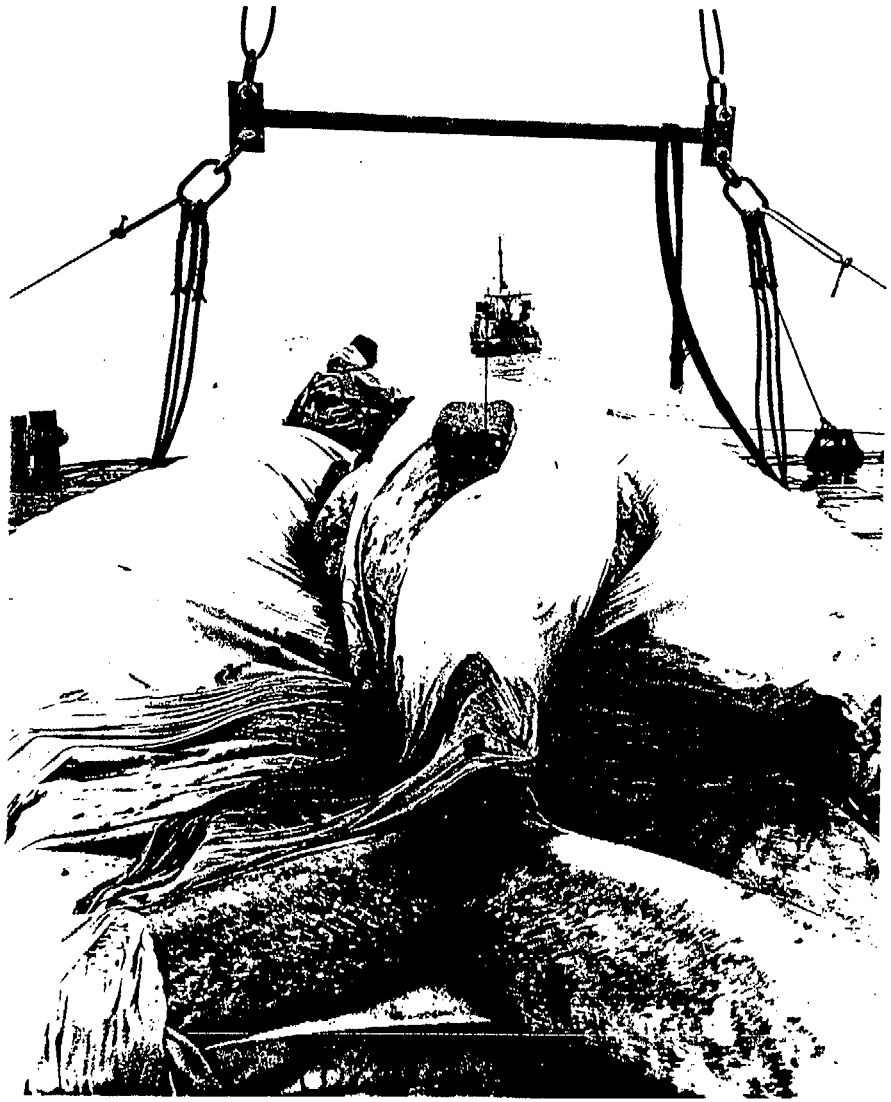

MFR PAPER 1059

Capture and Harnessing of Young California Gray Whales, *Eschrichtius robustus*

KENNETH S. NORRIS and ROGER L. GENTRY

ABSTRACT

This paper reports on the details of capture, harnessing, tracking, and harness release of three suckling gray whales. These tests are the first steps in a program to develop new means of data acquisition and recovery from whales during their migrations. It is hoped by these means to develop new information about population routes and hence population numbers to assist management. Capture was by tail noosing and head netting from a fishing vessel equipped with a swordfish plank. The harness, placed on the captive as [illegible], was held in place over the pectoral fins and back by means of a pair of metal plates held together by a soluble magnesium bolt. Tracking was by radio.

INTRODUCTION

Informed whale management requires adequate knowledge of population numbers. Uncertainty about migratory pathways and population mixing makes determination of such numbers uncertain for some whales such as the humpback (*Megaptera novaeangliae*), the blue whale (*Balaenoptera musculus*), the fin whale (*Balaenoptera physalus*), and the minke whale (*Balaenoptera acutorostrata*). Thus precise information on migration routes of these and other marine mammals would materially assist in the development of sound management practice (Anonymous, in press).

In spite of decades of work with Discovery and other tagging methods (Rayner, 1957) our knowledge of whale migration remains highly incomplete. Because such information is needed for some protected species, new tag

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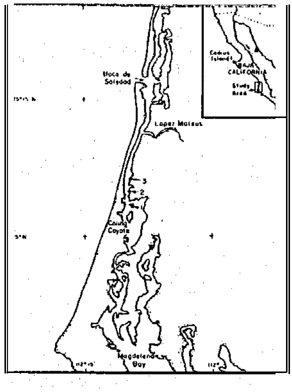

Figure 1.—Map of capture locality. Numbers indicate the capture sites for the three harnessed animals.

ging methods that do not require killing are now required. These methods seem to fall into two categories: (1) those involving the capture of whales, placement of harnesses and equipment on them, tracking along the whale's route, and subsequent release and recovery of data packages; and (2) those involving placement of data or telemetering packages on whales without capture, followed by tracking.

The first method will allow data collection from a few animals, while the latter will presumably allow less complete data collection from more animals and from those species that cannot be captured. The tests described here are of the first sort; that is, they involve capture and harnessing. The experiments of Evans (this number of *Marine Fisheries Review*) with Gigi are also of this sort, though surgical attachment rather than harnessing was used.

We chose our subject, the California gray whale, because large numbers of suckling calves are available in their Mexican breeding lagoon during January and February of each year and because the calm working conditions in the lagoon would assist these preliminary tests. We expect that the majority of results obtained on this relatively well-known animal will be applicable to more oceanic species. Our tests were restricted to capture, harnessing, and very short term tracking, since we expected that our results would require harness redesign prior to long-term tracking, This proved to be the case.

We attempted to capture suckling animals only because of the obvious dangers and seamanship problems presented by adult whales. The rationale supporting this choice is that a suckling calf, harnessed and instrumented, should keep station with its mother and, hence, give a true migratory route.

To our knowledge five baby gray whale captures or handlings have been reported. Eberhardt and Norris (1964) report working with a stranded baby gray whale in Scammon's Lagoon. Robert Elsner (pers. comm.) detailed a capture of a baby gray whale in Scammon's Lagoon from a small catamaran by use of a superficial harpoon followed by netting. David Kenney (pers. comm.) directed the capture of Elmer's animal and the capture and transportation of Gigi, the gray whale calf caught in Scammon's Lagoon and held for 12 months in Sea World. The latter whale was captured with a tail noose from a small fishing vessel equipped with a bow plank. The ship was reportedly damaged slightly by the mother when the baby was brought alongside. Theodore Walker (Cousteau, 1972) is shown manipulating a stranded baby gray whale in circumstances much like those discussed by Eberhardt and Norris (1964). Spencer (1973) reported on the drug-assisted capture of adult whales in Scammon's Lagoon.

THE STUDY SITE

We chose northern Magdalena Bay, Baja California Sur, Mexico, near Boca de Soledad for our work because of an abundance of whales living in a system of shallow bays and rather narrow channels and because

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the Mexican government has recently declared the better known Scammon's Lagoon (Laguna Ojo de Liebre) a whale reserve. Headquarters were established in the small government cannery town of Lopez Mateos, which fronts on the main lagoon channel 8 km southeast of Boca de Soledad (Figure 1).

In this region the channel is about 800 m wide and averages 11 m deep in mid-channel, To the west a low ridge of dunes separates the lagoon from the sea. The shore along the dunes drops precipitously into deep water. The eastern bank is typically bordered with dense mangrove thickets often cut by shallow bays and channels. The shore along the mangrove coast usually shelves gradually over a broad tidal flat to the main channel. This difference in bottom contour proved crucial to capture and harnessing.

While whales were found throughout the deeper parts of the channel, one concentration occurred just inside Boca de Soledad and another occurred at a broad expanse of water just north of Colina Coyote (see Figure 1). It was here, or somewhat closer to Lopez Mateos, that our captures took place. Our counts showed approximately 86 whales in residence in the entire channel system. Most were mothers and young, but a few males were present, as indicated by copulations observed inside the channel.

WHALE CAPTURE AND HARNESSING

Capture of suckling gray whales proved to be rather simple, once the basic techniques were established, Four whales were netted in 3 days (27-29 January 1973). One was released because it was clearly too large for our harnesses. The other three were successfully harnessed, released to their mothers, and tracked. Capture was performed from the swordfish boat *Louson*, a 15-m vessel equipped with a 11.5 m welded aluminum pipe pulpit projecting from its bow. During capture Captain Tim Houshar occupied the basket at the end of the pulpit, while the helmsman steered from a remote station atop the crow's nest. The vessel was maneuvered behind a whale pair, attempting to place the netman in the pulpit over the animals as they surfaced to breathe. At the same time another crewman in a speedboat zigzagged around and in front of the animals in an attempt to direct and distract them. This attempt succeeded often enough that surfacing whales rather regularly allowed the pulpit to pass over them. The tendency to surface beneath the pulpit varied rather widely from pair to pair and seemed most consistent in mothers with small young.

Once a pair surfaced under the pulpit a noose of 1.25 cm nylon line was placed over the small animal's head by means of a large metal hoop cut through at its outer margin and held together inside a piece of plastic tubing (Figure 2). The rather slow speed of the whales (usually less than 7 knots) and the relatively long time they spend at the surface during respiration make this a reasonably simple process.

At this point the nylon noose which was tied to the metal hoop with light twine was pulled loose. The hoop separated over the animal and was pulled away, leaving the noose to slip back to the tail stock of the little whale. Another crewman on the pulpit pulled the noose tight over the tail stock. The noosed young took out a modest amount of line, usually less than 100 m, before the line was belayed around a Samson post. The young did not dive for extended periods (less than 1 minute) but towed the vessel for a time in this position. The mother always stayed in close attendance, often sliding over the line or coming up underneath it, At times she lifted the young on her snout or back, and occasionally she thrashed at the restraining line with her flukes.

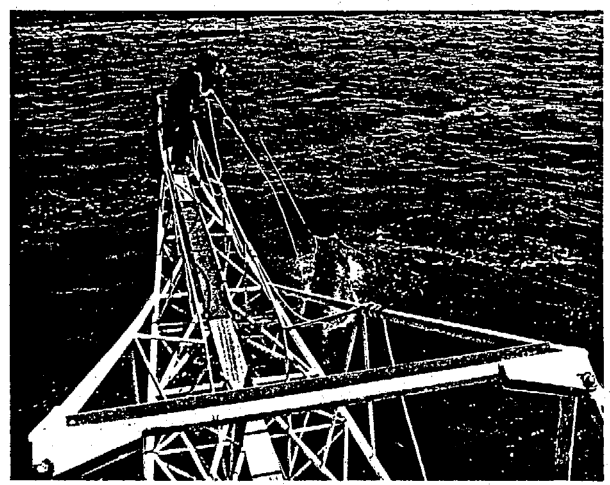

Figure 2.—Capture of the baby whale. Note hoop and noose being placed over the baby. Note also the swordfish plank which is maneuvered over the mother-young pair.

Once the young animal began to slow somewhat, it was brought back under the pulpit by bringing in line. The mother came with it and swam under the pulpit or slightly off to the side. Never did a female attempt to hit the boat or the pulpit, though our small sample may not be representative. A head net bag of 5 cm nylon mesh, also containing a noose of 1.25 cm nylon line and similarly positioned on a hoop frame, was placed over the baby's head. Optimally this net was deep enough to extend from the tip of the snout to just posterior to the pectoral flippers. In practice our nets were too small for all but one animal and placed the noose anterior to the pectorals. Even so, the noose did not slip loose.

With lines fore and aft the young animal was severely hampered and could be pulled in rather easily by hand. During this time the boat and skiff had been maneuvering the pair toward the east bank and its shallow shelf.

Two plastic trash barrels containing the coiled head and tail lines were lifted into a waiting skiff and payed out to the restrained whale until the shallow shelf was reached. Then the lines were taken ashore and the men, usually four to six, pulled the baby sideways onto the shelf. Usually the mother's efforts were strenuous at this time, and occasionally she looped the line over her body or tail giving an irresistible pull, but always she rapidly slipped free and the baby could be towed in again. The baby was beached in about 0.7 m of water, 10 m or so from the shelf edge. The mother was unable to enter such shallow water, though she did patrol the shelf edge, and in one case partially stranded herself, seemingly in an attempt to reach the baby, Thus protected from the obvious ire of the mother, it was rather simple to place the harness on the baby The danger from the mother was made clear when a crewman began working within a few meters of one The female whale lifted her tail, bent it back and thrashed the flukes around in a semicircle, horizontal to the water surface She missed the man by quite a distance but the force of the blow was enough to send a sheet of water over everyone nearby

The baby remained rather quiet during the harnessing process, The harness was usually slipped on under the snout and worked posteriorly to the pectorals which were then inserted through the harness. The harness was then tightened in place until snug over the baby's body. At this point, timing for harness release began as a corrosible magnesium bolt which held the release mechanism began to corrode away in salt water.

Three or four men pushed the baby back into deep water over the shelf taking care to avoid the mother. In all but one case she was nearby and quickly took up station with her off-spring. In one case the mother left before the baby was launched and was a kilometer or so down the bay shore when the baby began to swim in deep water. This baby cruised quietly for a short time and then, when about 300 m from the mother, turned as if on a signal and raced toward her. The mother did the same, turning toward the baby and beginning to swim rapidly Once they were near the mother circled the baby, thrashing the water with her flukes. It was probable that an acoustic recognition signal was involved. This young animal had been emitting short low frequency signals while stranded. Even if the young had become separated from the mother by some distance, chances for reunion remained excellent because of the restricted channels available for swimming

In all cases the presence of the harness had no visible effect on the behavior of the mother-young pair

HARNESS DESIGN

The harness was constructed of four layers of one-way stretch Lino 241,[1] commonly used in fabricating girdles and corsets, that permitted expansion and contraction around the whale's circumference. The two legs of each harness half (Figure .1) were attached together ventrally by "D" rings to a timed-release mechanism. Dorsally they were bolted to a curved metal plate holding the radio transmitter. Horizontal rows of grommets 5 cm apart in the heavy plastic-impregnated nylon reinforcing bond at the dorsal ends of the harness legs allowed adjustments to animals of different circumferences and allowed the harness to be secured under different degrees of tension. We pulled the harnesses snug on our animals, which prevented flutter from water passing around the swimming animal and kept the harness in place during dives (the harness was 40 cm wide and 112 cm long).

The strength feature of the harness was a 2 5 cm wide by (1.6 cm thick woven nylon strap in the leading and trailing edge of each harness half. These straps, held in sewn folds of the harness, were sewn to the harness only near the ventral "D" rings, thus permitting harness and straps to be adjusted independently to the whale's circumference. The grommeted ends of both the harness itself and the strengthening straps were attached to bolts on the dorsal plate by means of knurled nuts

A plastic cup on each side by mid-body simulated an instrument housing, and a polyvinyl chloride rod sewn across the harness above the pectorals acted as a batten, preventing bunching of the harness in the anterior-posterior direction.

The timed-release mechanism consisted to two aluminum plates held together by a central spring-loaded magnesium bolt. One plate had four tapered corner posts that fit into four receptacles on the other plate. The "D" rings of the harness legs slipped over the posts and over four strong springs that assisted in forcing the plates apart during jettisoning. All tensions of the harness and nylon straps were exerted against these posts. The magnesium bolt bore only the vertical strain of a spring between the two plates

The wall thickness of the magnesium bolt determined the interval between submergence in seawater and the time of breakage When the bolt broke the springs forced the two plates apart and released the "D" rings from their posts. Corrosion of the bolts was insured by a central copper sleeve that promoted rapid electrolysis.

The dorsal plate to which the harness attached was constructed of 5 mm curved aluminum, designed to fit over the body contour of a baby whale. An Ocean Applied Research Model PT-2(12 radio transmitter was secured to the center of this plain, and a painted yellow cap moulded of high density polyurethan foam was fitted over the transmitter for flotation. Foam neoprene sheeting was glued to the ventral surface of this plate to prevent chafing the whale's skin.

To fasten the harness around the animal, the two halves, connected ventrally to the timed-release mechanism, were slid under the animal and the pectoral flippers inserted through the harness. The radio, float, and plate were placed on the dorsal midline, and each harness half was pulled tight; the appropriate rows of grommets in the harness were fitted over bolts in the dorsal plate and the nuts tightened down. Then the excess rows of grommets were cut off with a knife and the heavy nylon straps secured in place and similarly trimmed. Finally straps from the float were attached, and the calf was ready to be launched to its mother Figure 4 shows the harness and radio in place as the released calf joins its mother.

[1] Reference to trade names does ... imply endorsement by the National Marine Fisheries S",",<" NOAA

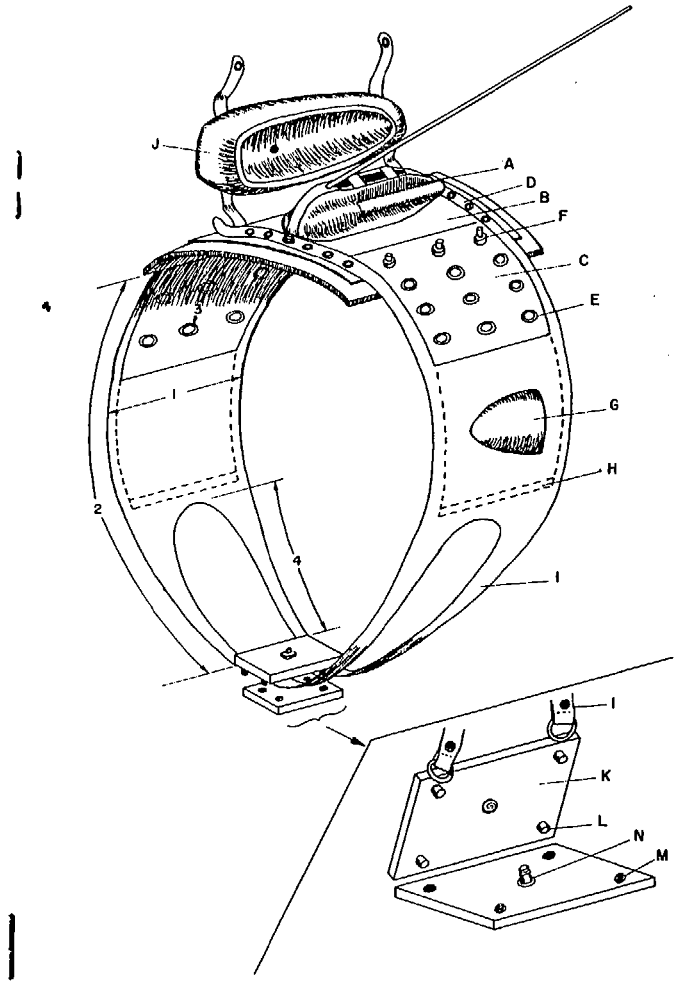

Figure 3.—The harness, radio transmitter and timed release mechanism: (A) OAR PT-202 radio transmitter (B) 5 mm curved aluminum dorsal plate (C) Plastic-impregnated nylon reinforcing sewn on harness of Lino # 241 material (D) Nylon reinforcing strap sewn into harness and bolted to dorsal plate (E) Rows of grommets (F) Knurled nuts holding harness to dorsal plate (G) Instrument housing (H) Polyvinyl chloride batten (I) Harness legs with "D" rings (J) Polyurethan flotation device attached by straps to dorsal plate (K) Timed-release mechanism (L) Aluminum corner posts to which "D" rings of harness legs attach (M) Receptacles for above posts—spring loaded (N) Magnesium bolt passes through spring loaded hole in top plate and secured with a nut.

Dimensions: (1) Harness width 40 cm (2) Harness length 112 cm from timed—release mechanism to first row of grommets (3) Distance between each of five rows of grommets ~ 5 cm (4) Length of harness legs 40 cm (5) Timed release mechanism 10 × 15 cm.

TRACKING AND HARNESS RECOVERY

The three harnessed whales remained within a few hundred meters of their release points (see Figure 1) Visual tracking in daylight was greatly assisted by the bright yellow float and upper harness which were visible even a foot or two underwater.

In the first release, after some time in the water, the calf swam purposefully toward the *Louson*, turned on her side, and rubbed the harness against the hull and keel of the boat -- breaking the float partly loose, releasing one "D" ring, and snapping the fiberglass radio antenna. Transmission of radio signals immediately ceased. This damage could have been prevented by our maintaining a greater distance from the harnessed animal. The timed-release mechanism contained a 5-hour bolt which had not released by the time darkness fell. The harness was recovered 2 days later in vegetation along the channel edge, about 2 km from the release point.

The second release, timed for somewhat less than 5 hours, went flawlessly, including radio tracking and harness release.

The third release was planned for 20 hours, with tracking overnight from the *Louson*. To assist after dark should the radio malfunction, a water-proof lifejacket light was fixed to the float. Though both radio and light functioned at release, they failed before

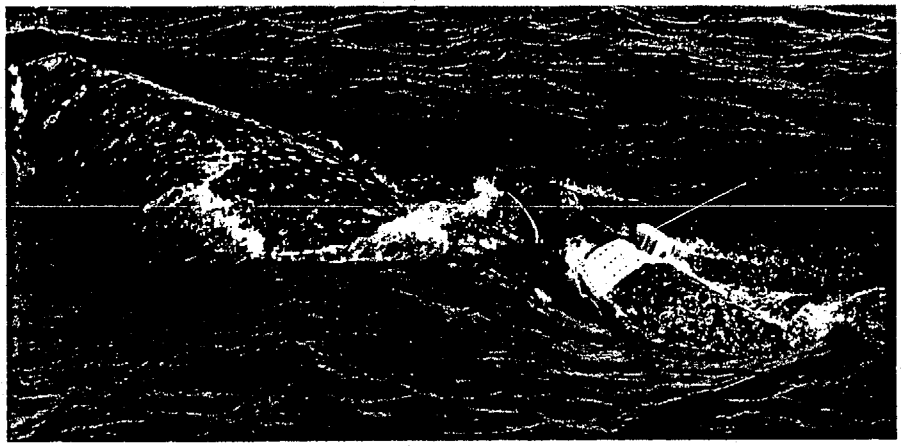

Figure 4.—Mother and young swimming with harness ● nd radio in place.

dark, and the animal was lost during the night. However, shortly after dawn the released harness was found floating within 60 m of the vessel. Details of these releases and trackings are presented in Table 1.

Table 1.—Harnessing and tracking of gray whale calves.

Date	Animal number and name	Sex	Girth (m)	Length (m)	Planned bolt life (h r)	Netting to beaching (min)	Beaching to release (min)	Tracking
1/27/73	(1) Carl(a)	F		2.41	4.20	5 ±	30 ± 37 ±	4 hr, 45 min track .,.1,,,. time uncertain
1/28/73	(2) Lee	M	2.17	420		5 ± 18 ±	14%	3 hr, 16 min
1/29/73	[31 Baja	F	2.51		5.16	20 ± 28 ±	8 ± 17	hr, 23 min to harness recovery. Time to release uncertain.

DISCUSSION

The capture methods described here for suckling gray whales are remarkably effective and simple. Except when the mother is under the pulpit or at the edge of shallow water, the methods seem relatively safe. Given enough shipboard power the noosing methods would work with larger animals, though the sheer bulk of an adult would make any movement by the whale, purposive or not, dangerous. This would certainly be a prime consideration in any attempt to affix a harness on an adult.

The harness described here would, with minor modifications, serve nicely for short-term tracking and instrumentation of small gray whales. Because a whale attains 66-72 percent of its adult size in the first year (Rice and Wolman, 197 l), growth during the first months is extremely rapid. Harnesses for periods of more than a week must therefore include a device that allows for growth but also keeps a constant tension and locks if the animal rubs the harness against underwater obstructions.

Another concern on any long-term track is abrasion of the harness. The purposive rubbing of whale No. 1 against the capture ship and its mother caused damage to the radio antenna and serious abrasion to the lower harness legs. On whale No. 2 the abdominal legs of the harness were abraded through the girdle fabric and into the flat nylon strap in several places, even though the animal wore the harness for only 3 hours, 16 minutes. Behavioral observations suggest that much harness wear results when the baby rubs against the barnacle-covered back of the mother and slides to one side as she surfaces. None of these problems was more than very minor in these tests. But clearly long-term tracking with increased exposure to obstacles along the migratory path will exacerbate these problems greatly. More durable materials, such as metal or the strongest fabric, and more resilient radio antennae will be needed for successful *long-term* tracking.

The release mechanism dependent upon magnesium bolt corrosion worked adequately, but variations in water temperature and salinity could unpredictably alter release lime. Long release times (more than a week) may require a new system. such as the use of electroexplosive or electronic release mechanisms that might allow an operator to release the harness upon command.

Harnessing is probably the least injurious means of attaching instruments to cetaceans, and harness placement around the pectoral flipper area is probably optimal. Pectoral placement insures maximum exposure of the antenna, minimal body movement during swimming. and relatively little change in girth during diving. Further, when physiological data are to be taken, most important vital areas (lungs. heart, brain) are nearby.

In our opinion package volume could be relatively high, providing it is weight compensated until nearly isostatic. A baby whale might well carry 15-20 kg of instruments property housed and shaped m reduce drag. Instrument placement is probably best just above or between pectorals where it would cause the least disequilibrium. In these positions it would be most difficult for the whale to rub the instruments loose. Any such package. of course, would have m be strongly protected from impact and abrasion.

The harness used here was designed with a float at the top to suspend the antenna with the harness hanging below so that when cast off it rode easily with the antenna in the vertical position for good transmission.

In conclusion. the first steps of whale capture and instrumentation have been taken, but much remains to be done m transfer the methods m (1) long term trackings. (2) other species which must be caught and handled at sea, and (3) adult whales.

ACKNOWLEDGMENTS

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We are especially grateful 10 Edwin Janss and Richard Wheeler of the Janss Foundation for support of the field study. A National Aeronautics and Space Administration subcontract No. 23196 (NASA NAS2-6860) allowed harness preparation.

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Opposite.—Gigi 11, with transmitter affixed to back, awaits release ● t ••• off San Diego. Photo by J. S. Leatherwood, courtesy of Naval Undersea Center, San Diego, cam.

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NEW TAGGING AND TRACKING METHODS FOR THE STUDY OF

MARINE MAMMAL BIOLOGY AND MIGRATION

Kenneth S. Norris, William E. Evans, and G. Carleton Ray

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CHAPTER 19

NEW TAGGING AND TRACKING METHODS FOR THE STUDY OF MARINE MAMMAL SI1OL.CCY AND MIGRATION

Kenneth S. Norris, William E. Evans, and G. Carleton Ray

Many aspects of our knowledge of marine mammal biology, including those important to management. rest upon shaky ground. This is not at all surprising to those 0 f us who attempt to gather such data. particularly upon the open sea. It simply isn't easy to work with these elusive, often bulky creatures from the unstable platform of a ship's dock . In fact, it is remarkable how much we have been able to learn about the large whales, for instance, as most data have been drawn from the nonrandom sampl ing of industry. Crucial data, especially on population identity and movements, remain to be gathered. This is as true for mar ine —L populations of precarious status as for exploited species . This paper concerns some new approaches that we feel will soon allow a fresh look at the biology of marine mammals and that will lead to better information on which to base management practices.

One of the most needed deve lopments is to design better instrumentation for tracking and telemetry. A vital part of any population study is information on movement and overal 1 range. Without such information it is impossible m assess the discreteness of various populations. Such data are basic for management on a sustainable yield basis. Most of our knowledge of large whale migrations has come through the use of Discovery marks—slim, numbered, metal cylinders shot into the whale (Brown 1962) . Data from these marks are limited; they are most useful for age and growth, but not so useful in determining movements, since only two points on the whale's track can be recorded, the point of marking and the point of death. Further, these two points are of ten in the same geographic area, since most marking has been done on the feeding grounds where the catch is also made.

Only rather recently have many marks been placed in whales far from the high latitudes (Site 1963; Clarke 1962). Even so, there is doubt about whether rorquals (Balaenopteridae) regularly cress the equator (Sli jper, van Utrecht, and Naaktgeboren 1964; Norris 1966) . It is also uncertain what routes most species travel. in their movements toward the equator—and whether they feed in temperate or tropical waters. Moreover, for most species there are few data which adequately strew the degree of mixing of the various migratory populations. Dawbin (1966) describes the mixing of various stocks of Antarctic humpback whales, *Megaptera*. Next to nothing, however, is known of commercial species of whales in the warm-water grounds of the open sea. To clarify these important questions, we need to trace the paths of whales with repeated fixes on marked individuals.

Scarcely anything is known of the movements of small porpoise and whale schools, except for those species involved in minor fisheries, such as tbe pilot whale *Globicephala* (Sergeant 1962) or for species currently being radio-tracked (Evans 1971 and chapter 18 of this volume) . The increasing importance of porpoises in commercial catches or as adventitious kills in the tuna fishery (Perrin 1970) makes the need for such data very great. It is reasonably certain that most of the smaller odontocetes do not migrate such hemispheric distances as large baleen whales, but it is also certain that in many places their local occurrence is seasonal; such data exist only for a handful of local populations , At this point it is fruitless to ask how big the population of a given porpoise species might be, what its recruitment is, whether or not its schools are units having temporal continuity, or what the natural fecundity and mortality levels are. It. is most important to learn to track these animals too—not on the basis of two points along their route, but in such a way that school intermixture, migration paths and speeds, and population numbers begin to become evident.

Finally, many other aspects of natural history are significant for informed management. One needs to know about growth and metabolic relationships in conjunction with knowledge of food sources and feeding behavior. We need information about, discontinuous distribution

as related to hydrographic features and primary and secondary productivity. Such information will help to determine whether localized exploitation decimates a population, or whether wider areas of the ocean must be managed. In addition, one needs to know when and where mating and calving take place, and how crucial environmental health is to whale population health. Must humpbacks came into shallow 'water to breed? Where do young gray whales (*Eschrichtius robustus*) go after birth (Rice and Wolman 1971)? What happens to breeding structure when familial or school relationships are disrupted by human exploitation? What factors influence infant mortality? A start "on gathering behavioral data was made on captive porpoises over two decades ago (McBride and Hebb 1948) and much has been learned since. but precious little has been gathered from animals in their natural habitats. Hence the technology of data-pack design and attachment to marine mammals is of much importance and promises to produce diverse and valuable information.

We will discuss three separate departures that are either operational or in design stages at present. Common to all three is the "*wing of marine mammals with data packs and/or radio beacons, and this is our subject here." Methods range from the use of radios on small cetaceans for subsequent tracking by boat or aircraft to equipping marine mammals with recoverable packages for data from shorter time periods and to instrumenting large whales for satellite tracking. There are two aspects which we will not discuss here; these are the r. f .' link, i.e. transmission of signal, and the receiving system itself. Both of these deserve special consideration, and their exclusion here is not to indicate their lesser importance. However, they are problems more electronic than strictly biological, hence their lesser emphasis here.

Radio-Telemetric Studies of Small Odontocete Cetaceans

The possibility of accomplishing the tasks previously discussed would have been speculation ten years ago. The feasibility of applying some of these techniques to the study of marine mammals in the field has now been demonstrated on a few species of small odontocetes. Techniques for the capture of these animals, developed principally by several oceanaria, have made possible the attachment of instruments to them for subsequent radio or acoustic monitoring.

Radio-beacon circuit designs, successfully used for several years in the recovery of untethered instrument packages at sea (Martin and Kenny 1971), provided the basis for radio-tracking and data-monitoring of delphinid cetaceans (Fig. 19-1). Within the past three years several common dolphins (*Delphinus delphis*), two pilot whales (*Globicephala scammoni*), one killer whale (*Orcinus orca*), and one Hawaiian spinner porpoise (*Stenella* cf. *longirostris*) have been successfully tracked at sea. The *Delphinus* (Martin, Evans, and Bowers 1971) and the *Stenella* (Norris and Dohl, in preparation) have been followed for as long as 72 hours. The *Stenella* tracking was accomplished with the equipment described by Martin, Evans, and Bowers (1971).

In addition to determining the movements of these individual, it has been possible to obtain the maximum depths achieved during each

FIGURE 19-1. A dorsal fin radio-beacon pack carried by Delphinus delphis. (Photograph by the U.S. Naval Undersea Research and Development Center.)

dive by telemetry (Evans 1971 and Chapter 18 of this volume). As an illustration of the potential of these technique, especially on the large whales, a summary of Evans's results follows:

(1) Schools of *D. delphis* follow and dive over prominent features of the ocean bottom (seamounts, escarpments, canyons).

(2) The depth of most *D. delphis* dives is clearly correlated with the depth of the vertically migrating, deep scattering layer (DSL).

(3) Herd movements of *D. delphis* appear to correlate well with seasonal shifts in populations of certain fish such as the northern anchovy (*Engraulis mordax*) and the Pacific hake (*Merluccius productus*).

(4) Although herds of *D. delphis* may spend several days in a restricted area, movements of up to 150 to 200 mi in a 48-hour period occur.

(5) Movement and diving behavior of *D. delphis* varies significantly as a function of light-dark cycles.

Data such as these exemplify how information on niche and habitat may be determined by using telemetric techniques.

Natural History Data Packs for Marine Mammals

In addition to tracking animals over long periods of time, there are specific shorter-term needs. Information on behavior and physiology is needed for single dives. The carrying capacity of the environment for any animal population is determined to a great extent by feeding behavior and trophoenergetics. The optimum way to gather such data is to record over shorter periods and in more detail than the aforementioned technique of radio-tracking allows.

Some work with data packs has been done by De Vries and Wohlschlag (1964) and by Kooyman (1966), who recorded dives of unrestrained Weddell seals (*Leptonychotes*) under Antarctic sea ice. Progress in telemetry (Mackay 1970; Fryer 1970) indicates that a recording instrument package could be developed to record several data channels for

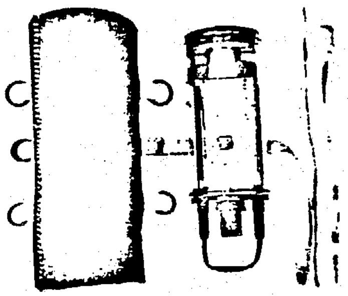

FIGURE 19-2A. A recording instrument package containing a tape retarder for recording both internal and external temperatures from an unrestrained pinniped. External leads to thermistors (not shown) are plugged into the bottom of the pack. A receiver picks up transmission from an internal pill. The entire pack is placed in the neoprene sleeve for protection. *(G. C. R. y photograph.)*

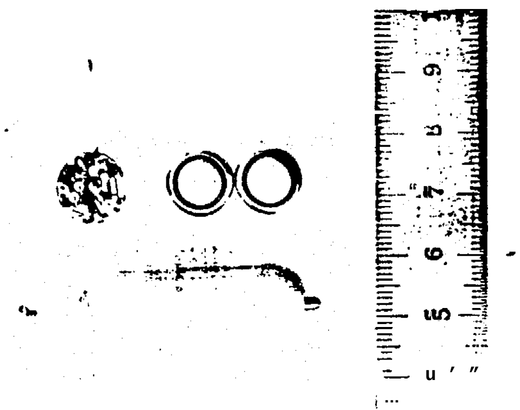

FIGURE 19-2B. A radio pill for transmission of internal temperature. The pill is enclosed in steel and coated with silastic. The antenna is a dipole. Shown above the pill are the transmitter (which is stable under changing conditons of temperature and voltage) and the batteries - (G. *C. Ray photograph.)*

later analysis. Formidable problems of miniaturization are partially obviated by the large size of most marine mammals.

Accordingly, in cooperation with Ocean Applied Research Corporation of San Diego, California. we have designed and built a data pack (Fig.19-2A) the purpose of which is to make hour-long recordings from free-swimming animals. A small tape recorder comprises the bulk of the data pack and determines the diameter of the tubular Plexiglass housing, which we have specified for 600 m water depth. A clock in the data pack switches it on at a preset time, whereupon the data are recorded on taPe. After the data pack is retrieved and the tape removed, demodulation of the data is by a deck unit and strip-chart recorder. Package retrieval implies the inclusion Of a radio beacon as a f eature of design.

The tape recorder largely determines the length of recording time - Such data as *temperature* may be recorded digitally, and tape speed may be *slow. However,* we also wish to record in situ sounds made by the animal, and this *must* be done *as* analog, for which tape speed must be much faster. A major design problem is miniaturization 'f the tape recorder for longer operation in the analog tie. Our present data channels include three for external temperature (two fOr animal skin surface and subsurf ace. one for ambient water or air temperature) • and a fourth for calibration. In addition, a radio pill (Fig - 19-2B) transmits internal (stomach) temperature, which tells two things, core temperature and f eeding (by a sudden drop in the temperature indicated) .

External temperatures are recorded by means of thermistors on wire leads. A difficult problem concerns desire of "pill" temperature transmitters with sufficient stability against variations in both voltage and the temperature of their surroundings. Some previous studies present data which appear suspect, but in very few cases are sufficient data presented On the electronics of circuitry. 'iii stability is discussed by Fryer (1970) , and Wartzok, RAY, and Martin (in press) discuss electronic design problems of this sort.

Attachment of the data pack is by a harness which has been developed for pinnipeds (Figs. 19-2A and 19-3}. Both otariid and

FIGURE 19-3. *A Steller sea lion, Eumetopias jubata, wearing the recording instrument package shown in Fig. 19-2A. The animal is a male of about 200 kg. (G. C. Ray photograph.)*

phocid seals can carry relatively large packages by this means. Attachment is a funct ion of body size, shape, and especial ly flexibility. The Package illustrated here is relatively simple electronically. The major problem is one of design and it was believed wise to solve problems of attachment, durability, and transmission from the internal Pill before adding other channels such as for heart rate, swimming speed, diving depth, and the like. Many of these data are obtainable with present technology and with only a moderate increase in size of the data pack. Also not to be forgotten • CW e nvironmental data such

as salinity, light levels, and other parameters which provide important environmental correlates to behavior and physiology.

Tracking of Large Cetaceans

Schevill and Watkins (1966) were the first to attempt radio-tracking of any cetacean. Radio beacons were attached from aircraft to unrestrained adult right whales (*Eubalaena glacialis*) with small darts imbedded in the blubber. However, m whale trackswere obtained.

A system is now being assembled that seeks to calve some problems involved in tracking large whales · and it is hoped that tracks will be obtained from animals over considerable periods of time. The data package is being designed by Robert M. Goodman of the Franklin Institute Research Laboratories, Philadelphia, California. The harness and capture and attachment techniques are being developed by K. S. Norris. Newborn mysticetes are much easier to catch than adults, being little larger than some odontocetes that are caught for oceanarium display. Gray whales have twice been successfu31 y captured (Robert Elsner and D. W. Kenny, personal communicat ions) , and one humpback whale calf has been maneuvered away from its mother and captured by the Oceanic Institute (Fig. 19-4). It seems probable that young of other whale species would be feasible to capture, especially the sperm whale, *Physeter*, and the slow-moving right whales.

The capture of the *Megaptera novaeangliae* calf occurred on 18 February 1970 from the R/V Holokai a few hundred ◻aters off Sandy Beach, Oahu, Hawaii. The mother and calf were pursued until the calf began to stay at the surface for relatively long periods. Then, as. the boat came near the pair, the calf veered away f rom its mother and came to the vessel's bow where it stayed while the coil-tors attempted to place a net over its head. It proved ck.tile, ref using to leave even when the collectors entered the water to adjust the net. The calf was brought aboard, measured (4.6 m long), photographed, and released to the cow, which remained nearby. When the calf was placed back in the water, it ● gain remained close to the Holokai, often touching the hul 1. Finally, it was led near the cow, whereupon the

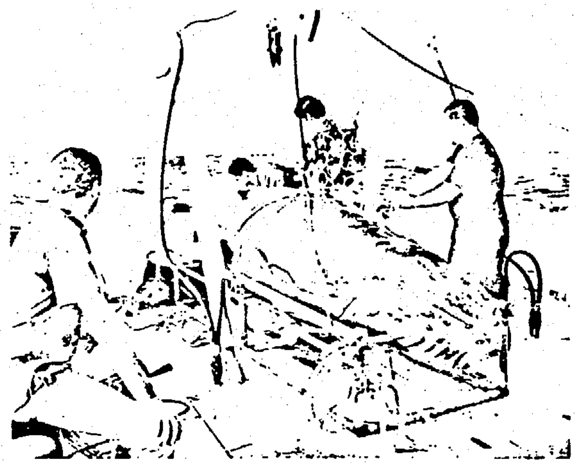

FIGURE 19-4. A humpback whale calf, *Megaptera novaeangliae*, captured by the crew of the R/V Holokai off Sandy Beach, Oahu, Hawaii, on 18 February 1970. (*Photograph by Chuck Peterson, Oceanic Institute.*)

calf strayed about 5 m away; the ship turned aside, and the calf quickly rejoined the cow. The pair then swam away together. The entire operation seems composed of two parts—a phase in which the younger animal is tired by forcing it to dive repeatedly until it remains near the surface, and the approach by the capture vessel, which should move only slightly faster than the swimming whales. The younger the calf, the easier it is to tire. Humpbacks only 2 m longer than this captive are much more difficult to separate from their mothers by this technique.

In our telemetric and tracking system, the package is to be attached to a harness which fits around the chest and is prevented from slipping by the pectoral fins. Such harnesses have been used on false killer whales (*Pseudorca*) (Fig. 19-5) and smaller porpoises. To avoid the problem of transmission from a moving animal which spends a great deal of time submerged and which is not likely to maintain

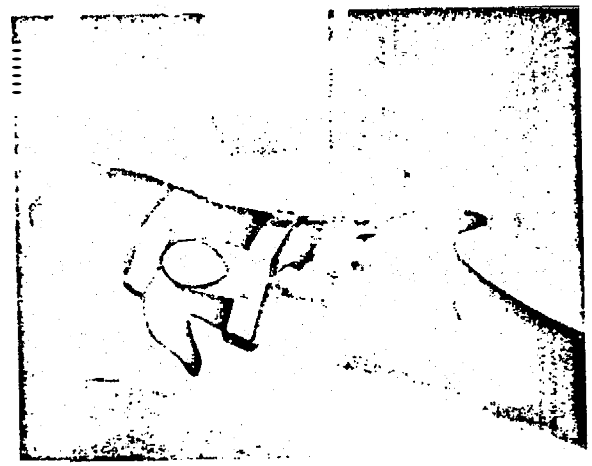

FIGURE 19-5. A pectoral harness on an adult false killer whale, *Pseudorca crassidens*, showing the position of the data pack. (*Oceanic Institute photograph.*)

the antenna in an ideal position for maximum efficiency, it is planned to equip the package with small jettisonable transmitters that will be released on a predetermined schedule. These will rise to the surface, erect a whip antenna, and transmit position data to a satellite, aircraft, oceanic buoy, or shore station. Since the calf will be released to its mother after attachment, and since the path traversed by the pair is presumably determined by the mother, we expect the course—if not the speed—of movement transmitted to be natural for both animals.

Meanwhile, another data package will be recording a spectrum of data about the behavior, physiology, and three-dimensional movements of the animal. After a predetermined period of several months, the harness and package will be released and relocated by radio beacon for retrieval. The following data will be recorded: pitch angle, magnetic heading, axial velocity, water temperature, axial magnetic vector magnitude, light level, heart rate, body temperature, acoustic output, and water conductivity. These will be recorded frequently and stored either digitally or as a Continuous analog on a spectrum recorder.

Conclusions

The central point we wish to stress 1s. that these electronic methods bid fair to provide data about many aspects of marine mammal biology which are otherwise unobtainable and which are important to management. Wildlife managers should achieve closer liaison with those developing these systems, so that information pertinent to their problems can be obtained. Further, these methods, though still experimental, will certainly be improved with use. Only a few workers arc developing these ways of gathering data from marine mammals. Notably, Or. T. Ichihara of the Far Seas Research Institute, Japan, has tested a high- frequency system (160 mHz) on a marine turtle (Ichihara 1971) which should soon produce useful results with cetaceans.

The systems described here are not the only potential new tools for tagg ing. It is possible to mark cetaceans for visual recognition. Perrin and Orange (1971) have used spaghetti tags Successfully in studying *Stenella* in the tropical eastern Pacific. Disc tags have been in use for some time (Norris and Pryor 1970) . In addition, Evans, Hall, Irvine, and Leatherwood (1972) have marked five species with discs, plastic streamers, and by freeze-branding. Such marks are often visible for considerable distances at sea. However, it has not yet been possible to provide a visual tag that can record complex data for a remote viewer to see. It must also be borne in mind that many cetaceans already bear individually distinct marks—for example, scars on the gray whale and the head markings (including the 'bonnet-) of the right whale. Nevertheless, in all cases involving a visual mark, long hours must be spent at sea in close proximity to the animals, and this is often an impossibility given the inconsistencies of weather and sea state.

Branding of small odontocetes was noted as early as 1953 (Tomilin 1960). Freeze brands, made by an Iron cooled in liquid nitrogen or another strong coolant, produce, on odontocetes at least, a very distinct white scar which is easily visible at sea. Such marks can be as large as the fin, in the form of numbers or symbols. They remain visible since the porpoise's skin remains free of algae and other organisms. Brands placed on captive *Stenella* at the Oceanic Institute, Hawaii, by Thomas Dohl at this writing have persisted for four years. Norris and Dohl are considering a band-held laser that might al low pl acement of coded marks without capture of the animal involved.

The idea of an aqe-specific mark is also sound. This would involve the injection of a marker compound from a Discovery-type mark, which will provide a visible band in bones or teeth during growth.

In conclusion, we need not be sat isf ied with present methods nor deterred by the expense and difficulties of new methods, some of which are still being designed. It is clear that the data we need in order to understand whale biology more fully must be obtained in new ways.

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AN EVALUATION OF TECHNIQUES FOR TAGGING SMALL ODONTOCETE CETACEANS

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ABSTRACT

Ninety tags — various combinations of radio tags, spaghetti tags, Roto tags, freeze brands, and tags bolted to the dorsal fin — were placed on 47 Atlantic bottlenose dolphins, *Tursiops truncatus*, captured near Sarasota, Florida, between January 1975 and July 1976. In 18 months of field observation, 910 tagged dolphins were sighted; 781 were identifiable, and 129 were not. Twelve naturally marked dolphins were also observed. Radio tagged animals were tracked for as long as 22 days. Repeated observations of tagged animals permitted evaluation of effect on animals and relative merits of the various tags. Freeze brands were most readable from a distance (≤30 m), and most long lived (1.8 years). Other tags were too short lived (bolt tags) or too small to be identified from a distance (Roto tags and spaghetti tags), and all caused tissue destruction. Radio tags caused unexpected dorsal fin damage and were frequently lost prematurely. Taken together, the results suggest that freeze brands are least harmful, and that static tags should be tested on each species to be studied prior to attachment in the field.

Cetaceans are difficult to study in the field. Most individuals move almost constantly, rise to the surface only briefly to breathe, and are difficult to differentiate from conspecifics. To facilitate individual recognition, researchers have developed several tagging techniques and tested them on small odontocete cetaceans. Nishiwaki et al. (1906) placed streamer tags on captive rough-toothed dolphins, *Steno bredanensis*, and concluded that none were effective. On the other trend Perrin et al. (1979) recovered spaghetti tags, another type of streamer, from free-ranging dolphins, *Stenella* spp., in the eastern tropical Pacific up to 1,478 d after attachment. Roto tags were placed on the spotted dolphin, *S. attenuata*, and one marked individual was repeatedly identified from a semisubmersible over a period of 3½ yr (Norris and Pryor 1970). Evans et al. (1972) successfully used radio transmitters, large plastic "button" tags, spaghetti tags, and freeze brands on a total of five species in the Pacific Ocean and Gulf of Mexico. Leatherwood and Evans (1979) have recently reviewed developments and uses of radio tags on cetaceans. Irvine and Wells (1972) reported that an improved button tag was sighted 3 mo after attachment to a bottle nose dolphin, *Tursiops truncatus*, near Sarasota, Fla. Despite all these improvements in tagging technology, however, little information has been available about long-term effectiveness or affect on the wearers of any type of tag.

The tagging program of Irvine and Wells (1972) was reinitiated in the same area in January 1975, after a 4-yr lapse. Using radio transmitters, visual tags, and natural marks we studied the movements and activities of bottlenose dolphins. Between 29 January 1975 and 25 July 1976, 47 dolphins were captured, tagged, and released a total of 90 times. A summary of the tagging program and an evaluation of the tagging methods used are included below. Detailed analysis of the tagging program results is presented by Irvine et al. (1979,[4] 1981).

METHODS

The study was conducted along 40 km of coast south from Tampa Bay, Fla. The study area included shallow channels and bays hounded by a chain of barrier islands (NOS Chart No.

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[4] Irvine, A. B., M. D. Scott, R. S. Wells, J. H. Kaufmann, and W. E. Evans. 1979. A study of the movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, including an evaluation of tagging techniques. Available National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151 as PB 298 042, 54 p.

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11425). Dolphins were captured by encircling one to nine animals with a 455 m X 4.5 m net dropped from a fast moving boat in shallow water. An inner circle enclosure method (Asper 1975) was used to minimize escapes. The inner circle was partitioned so that individual dolphins could be isolated and entangled without collapsing the entire net on remaining animals. Tangled dolphins were removed from the net and placed for tagging in a stretcher, usually held in the water alongside a boat. All animals were sexed, measured, and photographed before tagging. Previously tagged dolphins were examined and retagged as necessary before being released.

The study area was surveyed as thoroughly as possible at least biweekly in a 7.3 m Wellcraft Fisherman[5] boat equipped with a 3 m tuna tower. All dolphin sightings were recorded during 228 surveys photographs were taken to facilitate identification of tags and distinctive dorsal fins.

Radio Tags

An improvement (Model PT 219) of the radio tag developed for small pelagic cetaceans by Ocean Applied Research Corporation (Martin et al. 197 1) had not been tested on *T. truncatus*. In our first efforts, the transmitter was attached with plastic straps to a foam-lined fiber glass saddle and secured to the dorsal fin with a stainless steel bolt through the fin. Because saddles provided by the manufacturer were too small for most *T. truncatus*, the transmitters were attached to fiber glass saddles molded by the authors (Fig. 1A, C). The saddles were lined with open cell foam to protect the animal from abrasion and to allow water circulation for thermoregulation.

Transmitter saddles were attached using techniques developed by other i nvestigators (see review by Leatherwood and Evans 1979). The first seven saddles *were* attached with single bolts through the dorsal fin. The last three saddles were attached with bolts fore and aft to provide greater stability against water flow (Fig. 1C). Spring-loaded bolts with dissolving nuts were designed to release the saddle and transmitter from the dolphin sometime after the 1-2 mo life of the lithium batteries.

Ten radio tags (designated RT-1 through RT-10) were attached to dolphins between 29 January 1975 and 9 June 1976. The RT-1 transmitter consisted of a single 35 cm long X 3.7 cm diameter tube with a 63 cm high spring steel antenna on the forward end. Transmissions from RT-1 gradually failed within 2 h, apparently due to saltwater leakage intu the battery case. Cause of failure could not be confirmed because the transmitter was missing from the saddle when it was sighted 2 d after attachment. Transmitters on subsequent radio tags were. attached to the saddle with bolted aluminum plates (Fig. 1A, C) instead of plastic straps.

The transmitter antenna on RT-2 was observed to be broken off at the base 5 d after attachment. Consequently, transmitter packages on RT-3 through RT-10 were modified to two tubes, 19.2 cm long X 3.8 cm diameter, connected by copper tubing at the forward end. A flexible 42.5 cm high whip antenna extended vertically from the rear of the starboard tube. The tubes, with transmitter assembly in one and batteries in the other, were bolted to either side of the saddle, and the connecting tubing was solidly encased in fiber glass (Fig. 1C).

Visual Tags

The button tags described by Evans et al. (1972) had proven not to be durable on *Z'. truncatus* (Irvi ne and Wells 1972). Therefore, we elected to try rectangular fiber glass "visual tags" (Fig. 2). These tags were 10 cm X 7.5 cm and made of 0.4 cm thick yellow laminated fiber glass with 5.1 cm high black tape numerals epoxied to the surface. Each tag was held in place by Teflon bolts w ith stainless steel washers and cotter pins. The bolts were placed near the anterior edge of the tag to produce a streaming effect as the dolphin moved through the water. The bolt hole was bored through tbe fin and cauterized with a heated rod, and sheathed with Plexiglas tubing in the *same* manner as for radio tags.

Double bolt tags, also yellow rectangles with black numerals, were cut from 0.2 cm thick fiber glass and varied in size from 9.0 cm X 12.9 cm to 10 cm X 15 cm, depending on the size of the dorsal fin to be tagged. The bolts were located near the anterior and posterior edges of the tag. Numerals were 7.7 cm high. Because cotter pins had sheared some of the Tef lon bolts on single

[5]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA. or the U.S. Fish and Wildlife Service.

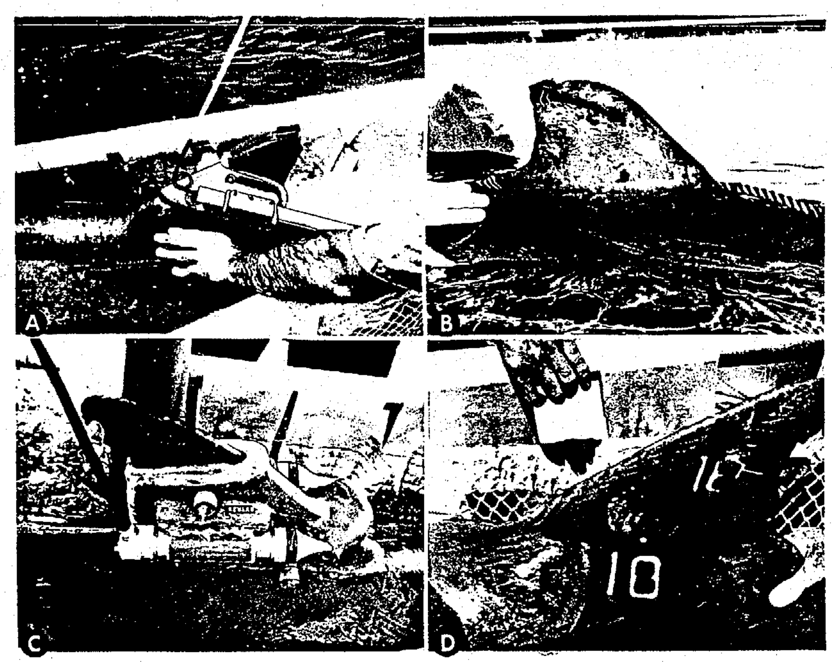

FIGURE 1.—A. Single tube transmitter wilh spring antenna forward (on dolphin RT-2). B. Dorsal fin 8 mo after transmitter in A was attached. C. Twin tube transmitter assembly with whip antenna aft. Dissolving nuts are top center and below the forward portion of the tube. D. Dorsal fin from C 22 d after the transmitter's installation. Note discolored, apparently necrotic. area around forward hole and apparent migration path of top bolt.

bolt tags, double bolt tags were attached with 0.64 cm stainless steel bolts and nuts.

Freeze Brands

When first captured, all dolphins were freeze branded with 5 cm high numerals on both sides of the dorsal fin and on the body below the fin (Figs. ID, 2C, D). Recaptured animals were rebranded as necessary to improve visibility of existing brands. Application times of 15 s with irons cooled in a mixture of Dry Ice and alcohol *were* used to brand the dolphins captured before August 1975. Thereafter, liquid nitrogen was used as the coolant. The application time remained 15 s. When possible, the skin was rubbed with an alcohol swab to lower the skin temperature by evaporative cooling prior to branding. Before April 1976, the branding irons were applied to the skin with a gentle rocking motion to assure *even* contact. After that time the irons were held firmly against the skin without motion, and brand visibility was greatly improved. In some cases, however, parts of the brand did not show because of uneven contact (Figs. 1D, 2C, D),

Roto Tags

Numbered Roto tags (NASCO Inc., Ft. Atkinson, Wis., Jumbo size) were attached to the trailing edge of the dorsal fin of all dolphins handled after January 1976. Red tags were attached to females and yellow tags to males. The

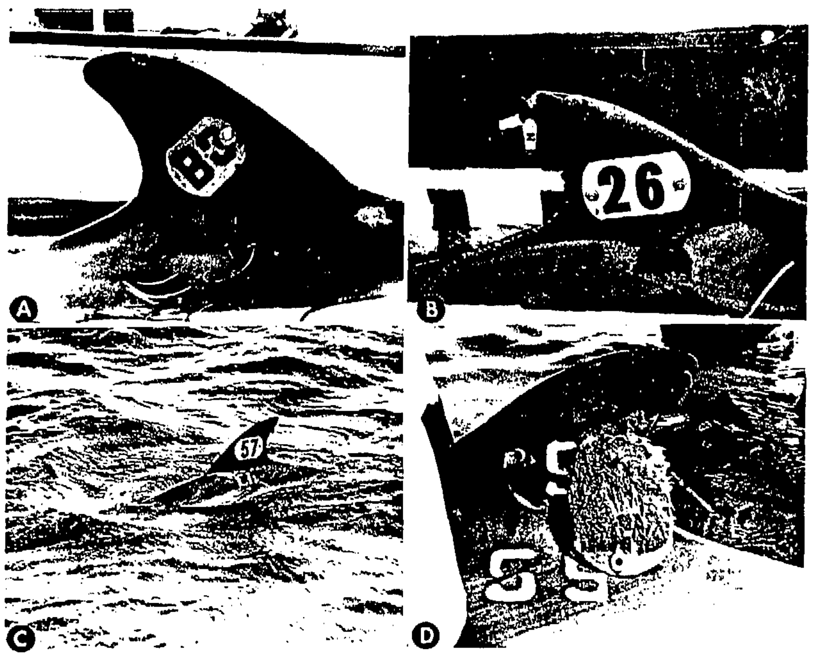

FIGURE 2.—A. Single bolt visual tag held by Teflon bolt and cotter pin. Note tag bolt scar from 1970-71 study B. Double bolt tag, Roto tag (at top rear of fin), and spaghetti tag (lower right) C. Double bolt tag on free-swimming dolphin Note freeze brand with incomplete left digit ." body below fin D A lgae-covered tag 2 m. after initial installation. Note indented area of skin where water flow against tag on opposite side of fin caused pressure on near side. Note also discolored tissue around forward bolt hole

TABLE 1.—Comparison of tagging techniques

1 ." no	No tags installed	Tag longevity[1]	No sightings/tag mean	No sightings/tag total	No identifications/tag mean	No identifications/tag total	% identifiable sightings-other observers	No tags of known fate	Tags of known fate lost, broken, or removed %	Tags of known fate lost, broken, or removed total no	Tags of known fate obscured by fouling %	Tags of known fate obscured by fouling total no	Tags of known fate removed " . , " of tissue damage %	Tags of known fate removed of tissue damage total no
Visual tags (single bolt)	16	< 5 min to >2 mo	4 88	78	2 00	32	6	14	86	12	14	2	14	2
Visual tags (double bolt)	19	< 2 wk to >2 mo	10 00	190	9 84	187	16	16	8 3 ,	" 3	1 5	?	5	4
Roto tags	53	< 1 d to >5 5 mo	6 45	342	053	70	0	48	40	19	10	5	4	2
Spaghetti tags	17	1 mo to >13 mo	2 53	43	0		0	12	5	0	6	0	25	3
Freeze brands	[2]47	>4 8 yr	6 57	309	5 89	277	2	39						
Natural marks[3]	1 ?	>6 yr	7 25	87	7 25	87	1	12					-	-

[1]Length of time tag was attached and identifiable
[2]Many were redone or touched up"
[3]Recognizable dorsal fins

numbers on the tags were too small to be rend from the observation boat, hut the color codes were useful for recognition of sex, and the positions of a tag often indicated identity.

Spaghetti Tags

Spaghetti tags (Floy Tag and Manufacturing, Inc., Seattle, Wash., Model FH 69A) were tested on some dolphins captured from April through June 1970. The, attachment technique was similar to that described by Evans et al. (1972), except that the tags were applied to ani reals i n a stretcher.

Natural Marks

Some dolphins had disfigured or uniquely shaped dorsal fins. A photo catalog of these recognizable untagged animals was compiled as a reference for field identification.

RESULTS

Nine hundred ten tagged dolphins were sighted; 781 were identifiable, and 129 others were not. When field identification wua uncertain, photographs of combinations and locations of tugs or tag remnants were often examined to verify individual identities. A compilation of tagging and sighting results is presented in Table 1.

Radio Tags

Ten dolphi ns were radio tagged and tracked for up to 22 d (Table 2). Eight of these were later recaptured and examined. In five instances, the saddle was lost, apparently because the bolt ripped through the fin (for example, see Figure 1B). Fin damage was apparent 3 to G wk after tagging by which time saddles no longer fit snugly over the leading edge of the fin. When loosened, the saddles titled backwards creating an obvious drag; this shifting caused the bolts to migrate dorsoposteriorly. When RT-8 was recaptured after wearing a transmitter for 22 d, the two bolt holes had not healed nor appeared infected. The forward bolt had migrated dorsoposteriorly about 1.6 cm (Fig. 1 t)), and the saddle was fouled with algal growth and monofilament line. When RT-9 wsa recaptured after 46 d, the saddle and rear bait were missing, but the front bolt waa still present but bent, with part of the disserving nut attached. The partially healed wounds appeared discolored and necrotic, but showed no obvious signs of infection. Only RT-6 showed *no* fin damage from the radio *tag,* but the tag (with malfunctioning transmitter) was removed <8 h after attachment.

Two dolphins, RT-9 and RT- 10, developed aberrant swimming behavior after 10 and 17 d, respectively. Both animals were observed to respire without bringing the dorsal fin to the surface in a typical cetacean rolling motion, although each could move rapidly under water. Evaluation of the problem was impossible because RT-9 evaded recapture attempts during this period, and RT-10 waa not sighted during capture operations.

One animal, RT-7, died 17 d after tagging, apparently of causes unrelated to the radio tag. Necropsy results implicated pulmonary damage from parasitism as a cause of death. It could not be determined if the capture-taming process contributed to the cause of death. Tissue autolysis precluded histopathological examination, and no parasites were found.

TABLE 2.—Radio tagging results.

Tag no	Tag description	Dolphin sex	Dolphin length (cm)	Date attached	Duration of transmission	Probable reason for cessation of transmission
RT-1	Single cylinder, forward spring antenna	Male	251	"20 Jan 1975	2 h	Water leak (?)
HT. >	Single cylinder: forward spring antenna	Male	210	28 Apr 1975	5 d	Broken antenna
RT-3	Twin cylinder; aft spring antenna	Male	24S	15 Jun 1975	20 h[1]	Seawater switch failure (7)
RT-4	Twin cylinder, aft flexible antenna	Female	252	, Aug ,975	6 d[2]	*unknown*
RT-5	Twin cylinder, aft flexible antenna	Female	257	70.1 1975	7.5>	Seawater switch failure *(?)*
RT-6	Twin cylinder, aft flexible antenna	Male	226	15 Dec 1975	7 h	Seawater switch malfunction; transmitter removed
RT-7	Twin cylinder; aft flexible antenna	Male	239	14 Feb 1970	17 d	Functioning transmitter removed from dead dolphin after 21 d
RT-8	Twin cylinder; aft flexible antenna	Male	221	15 Apr 1976	27 d	Functioning transmitter removed because of fin damage
RT 9	Twin cylinder, aft flexible antenna	Female	250	8 May 1976	10 d	Unknown. Dolphin did not bring fin above the surface
RT .,0	Twin cylinder, aft flexible antenna	Female	250	9 June 1976	17 d	Unknown Dolphin did not bring fin above the surface

[1]Inconsistent signals during the last 6 h
[2]Direction finder malfunction after 6 d
[3]Inconsistent ,10..186880..2 the last 3 d

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Visual Tags

Sixteen single bolt tags were attached between January and December 1975. One was lost within seconds, and three others were lost within 24 h. Two tags had twisted after 2 mo, damaging the fin and requiring removal of the tag. Another tag was believed to have ripped through the fin of a third animal. Two recaptured dolphins had bolt migration scars, and the tags were lost. Of 32 single bolt tags identified in the field, only 3 were sighted more than 2 wk after tagging.

From December 1975 through May 1976, 19 dolphins were tagged with double bolt taga. Tags were identified on free-ranging dolphins 187 times through July of 1976, and one tag was sighted 2 mo after attachment. Broken tags wet-e observed eight times, and nine sightinge were unidentified due to algae and barnacle fouling (Fig. 2D). Several tags were observed to have only the upper anterior edges broken, implying that breakage was from physical contact. During recaptures, four intact taga were removed because barnacles on the inner surface of the tag caused skin abrasions. Six broken taga were removed. Bolt migration was not as common as with single bolt tags, probably because of the stability offered by the rear bolt. Although none of the bolt wounds appeared fully healed, none appeared infected when the animals were recaptured and examined.

Visual tags were often discernible up to 200 m away. The numerals were rarely readable at distances >50 m, but even broken tags, tag bolts, and tag scars were useful for identification nf some dolphins.

Freeze Brands

Freeze brands were recognizable on marked animals at distances of <30 m, although photographic analysis was often necessary to confirm identification. Some brands were difficult to identify because they were incomplete or because of the relatively ponr color contrast nf the brand against the skin (Figs. 1D, 2C).

One of the dolphins captured by Irvine and Wells (1972) in March 1971 and freeze branded (nn botb sides of the dorsal fin) was captured again in December 1975. The animal had a readable freeze brand on only one side of the fin. On another dolphin branded in the same manner in March 1971 and additionally recognizable because of a deformed lower jaw, the brand was readable in May 1971 (Evans et al. 1972), but the brand was no longer visible upon recapture in February 1976.

Roto Tags

From February 1976 through July 1976, 53 Rota tags were placed on 38 dolphins, including 3 animals released with 2 tags. Roto taga were known to be lost from 17 animals and were replaced on 10 of them. A healed indented notch on the trailing edge of the fin was the only evidence of tag loss. Two Roto tags were replaced due to barnacle fouling on the inner surfaces. Brown algae and/or barnacles obscured the tag numbers on most recaptured dolphins, but the tags were still readable on close examination.

Roto tag color could be observed from up to 70 m in calm seas. When examined photographically, position of the tag on the fin or placement in relation to other tags or marks helped verify identity. No dolphins were identified exclusively with Roto tags.

Spaghetti Tags

Seventeen spaghetti tags were attached to 13 dolphins, including 4 dolphins initially released with two tags. None of the animals reacted noticeably to the attachment process. Six tags were missing from four animals recaptured 10 wk after tagging. Three tags were removed from three other dolphins because the entry wounds appeared to be festering.

Animals that had lost their tags bore healed but discolored scars that were similar in size to the festering entry wounds described above. No scratches or other evidence that the dolphins may have attempted to remove the tags by rubbing were noted. The wounds, up to 1.9 cm in diameter, apparently were created by movement of the base of the tag streamer on the skin.

One spaghetti tag was observed in May 1977, 345 d after attachment. Several orange colored spaghetti tags became faded within 4 wk, an observation not reported by other investigators.

Natural Marks

Twelve untagged dolphins with recognizable natural marks were identified a total of 87 times. Photographs of an individual taken first in 1970-71, then during this study in 1976, and by Wells et al.[6] in 1980 suggest that natural marks are relatively permanent.

DISCUSSION

The most obvious shortcoming of tags attached to the dorsal fin was the short longevity. Water drag, tissue rejection, and attempts by dolphins to shed tags may have contributed to tag loss and fin damage. We had hoped that tissue would grow tightly around the bolt sheatha and insulate the wound from bolt-induced tissue irritation; however, healing apparently never occurred while bolts were in place. Since tag wounds did not heal, different attachment methods or new designs are needed. Transmitter packages on two killer whales, *Orcinus orca*, were held for 6 mo by pins implanted diagonally to the plane of the leading edge of the fin (Erickson[7]), and may offer an alternative method of attachment. The relatively larger fin of a killer whale (vs. a dolphin) may, however, have increased chances of success. Carbon bolts attach human prosthetic devices[8] and are another attachment method yet to be tested on marine mammals.

Radio tags have proved useful to study the ecology of small odontocetes (Evans 1971, 1974; Evans et al. 1972; Gaskin et al. 1975; Würsig 1976), but the configuration used in this study is not recommended fnr use on *T. truncatus*. The fin damage, premature transmitter *loss, and* unusual swimming behavior which we observed, may influence study results. These factors have not been previously documented. Radio tags caused nn obvious behavioral effects during captive tests on *Delphinus delphis* (Martin et al. 1971). In field studies, however, the radio tagged animals have been infrequently sighted and never recaptured, so possible long-term effects of the tags on the animals are unknown.

Freeze branding proved the most durable marking method. The variability of marks on the animals captured 5 yr after branding indicates that tissue response to the branding process is inconsistent. Freeze brands have remained readable after several years in captivity, but optimal coolants, application times, and pressures have yet to be determined (Cornell et al.[9]). Our refighting, after almost 5 yr, is the longest yet reported. Twenty-one of 26 of the dolphins originally tagged in this study were observed during 1980 and had freeze brands that were either completely readable in photographs or were legible enough to confirm identifications indicated by other characteristics (Wells et al. footnote 6). Maximum longevity of freeze brands is still unknown, however.

The comparatively high incidence of spaghetti tag loss reported here is noteworthy because this tagging method haa been previously used with no reports of rejection or abscess (Sergeant and Brodie 1969; Evans et al. 1972 Perrin et al. 1979). Recent tests on captive dolphins have shown, however, that tag loss may be related to tissue rejection, attachment impact, or to the angle of dart entry (Jennings[10]).

Recognition of natural marks provided useful supplementary information in our study, and bas been used to study bottlenose dolphins in Texas (Gruber 1981; Shane and Schmidly[11]) and Argentina (Würsig and Würsig 1977). Close approach to the animals is usually required for field recognition, however, and we felt that photoidentification was necessary to verify most of our sightings.

This tagging study bas demonstrated that repeated sightings of tagged dolphins are possible and can provide substantial amounts of information about the behavioral ecology of small cetaceans (Wells et al. 1980; Irvine et al. 1981). Selection of the tags to be used should, however, involve consideration of tagging and refighting effort, tag visibility and durability, and potential harm to the tagged animal. Visual

[6]Wells, R. S., M. D. Scott, A. B. Irvine, and P. T. Page. 1981. Observations during 1980 of bottlenose dolphins. *Tursiops truncatus*, marked during 1970-1976, on the west coast of Florida. Report to National Marine Fisheries Service, Contract No. NA80-GA-A-195, 21 p. Available Center for Coastal Marine Studies. University of California, Santa Cruz, CA 95064.

[7]Erickson, A. W. 1977. Population studies of killer whales (*Orcinus orca*) in the Pacific Northwest: a radio-marking and tracking study of killer whales. Available National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151 as PB-285615, 34 p.

[8]Anonymous. 1977. The application of high purity carbon technology for Rehabilitation Engineering Center at Rancho Los Amigos Hospital. John F. Kennedy Space Center (NASA) Report SE D-77-100, 146 p. Kennedy Space Center. Cape Kennedy, FL 32899.

[9]Cornell, L. H.. E. t). Asper, K. Osborn, and M. J. White. 1979. Investigations on cryogenic marking procedures for marine mammals. Available National Technical Information Service, 5285 Port Royal Road. Springfield. VA 22151 as PB-291570. 24 p.

[10]J. G. Jennings. Fishery Biologist, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271. La Jolla, CA 92038, pers. commun. October 1978.

[11]Shane, S. H., and 1). J. Schmidly. 197s. Population biology of Atlantic bottlenose dolphin, *Tursiops truncatus*, in Aransas Pass, Texas. Available National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151 a.. PB-283393. 130 p.

tags are most detectable, but are nut durable and may damage the dorsal fin tissues. Freeze brands are durable, but not highly visible. Roto trigs are of limited use for field identification except in unusual close range situations (e. g., Norris and Pryor 1970), although a combination color and location of the tag can identify an individual. For free-ranging dolphins, spaghetti tags are the only current tagging option, but identification nf these tags usually requires collection of the animal. If animals are to be captured initial ly, combinations nf tag types and use of natu ral marks can provide effective field identification.

Although radio tagging and tag or mark identifications are valuable tools for ecological studies of cetaceans, more development and tinting of tags and attachment techniques are needed. Investigators should realize that tagging methods which are successful on one species may not work well on another species. Prior to field studies, tags should be tested on the species to be studied. We also recommend intensive follow-up sighting surveys to maximize data return and to determine the effect Of tags und marks on free-ranging animals.

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POPULATION STUDIES OF KILLER WHALES (Orcinus orca) IN THE PACIFIC NORTHWEST

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.

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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 congenia 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 milliwatts. 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 imer 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 trans - mitter 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 8S0 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 tbe 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 stain- less 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 esti - mated 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

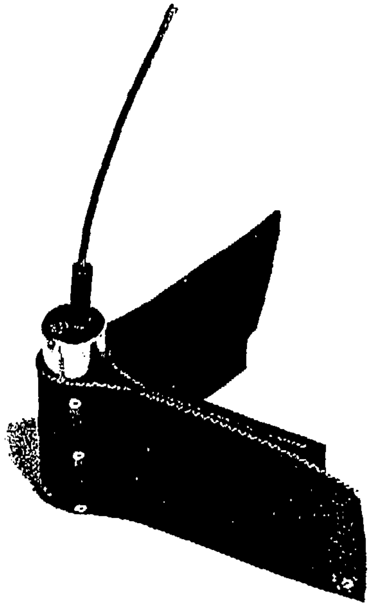

Figure 2. Design of the radio pack installed on the female killer whale.

Figure 3. View of the San Juan Island Kanaka Bay holding pen at [illegible]

killer whales to be instrumented could be held for a period of time. The site selected and developed was a small unnamed bay located adj scent 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-feet 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 z 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 autoclave 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.

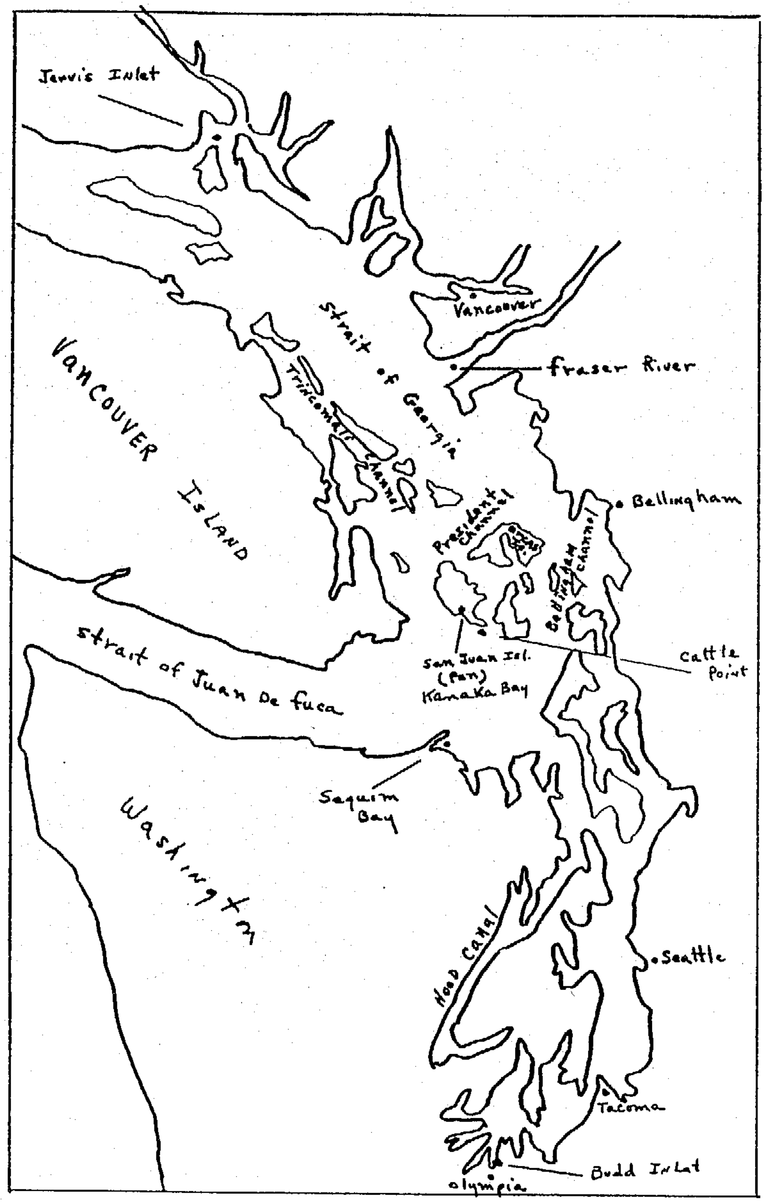

Figure 4. Map of Puget Sound, Juan de Fuca Strait and the Strait of Georgia.

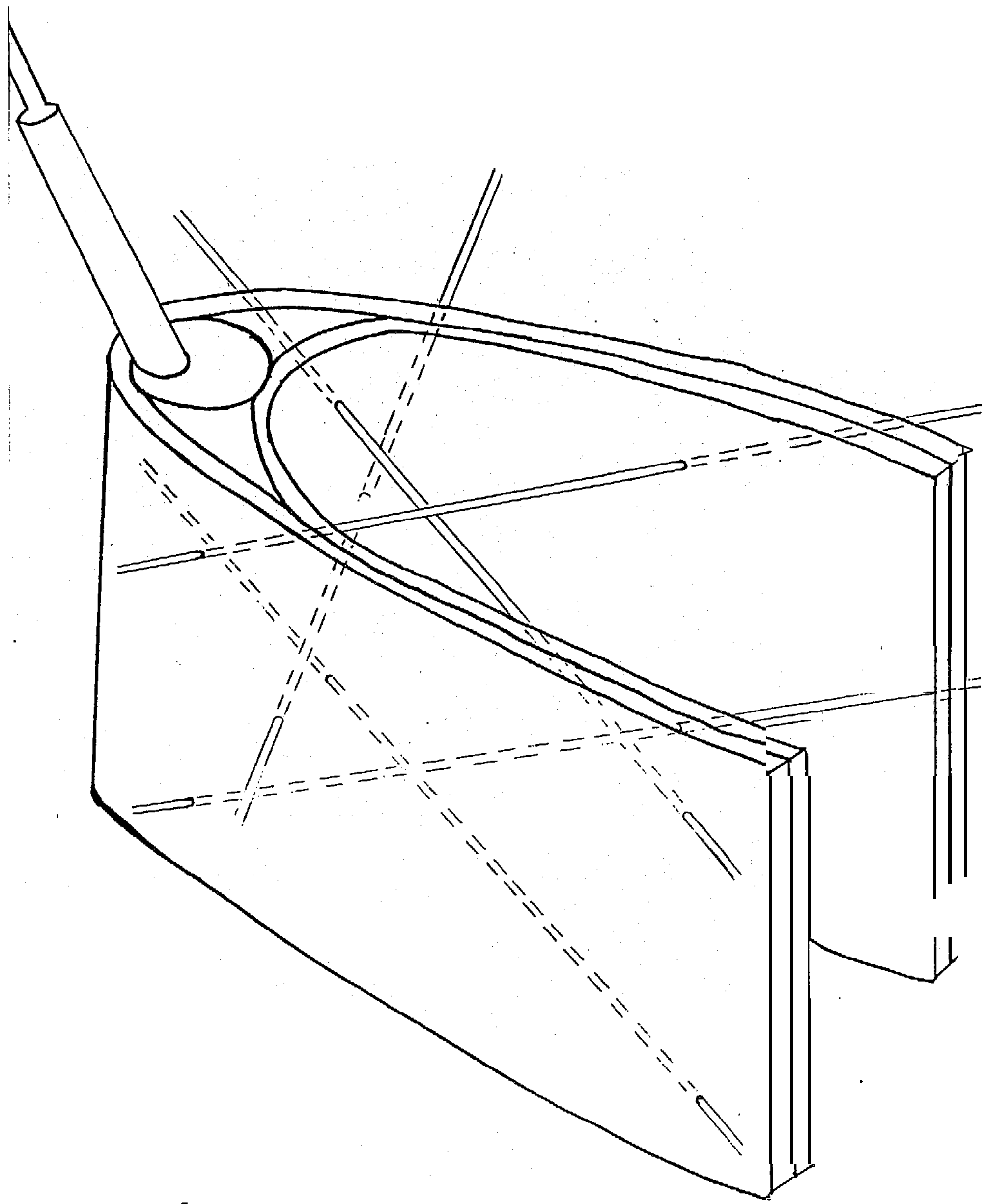

Figure 5. Schematic illustrating procedure by which radio pack was pin-attached to the female killer whale.

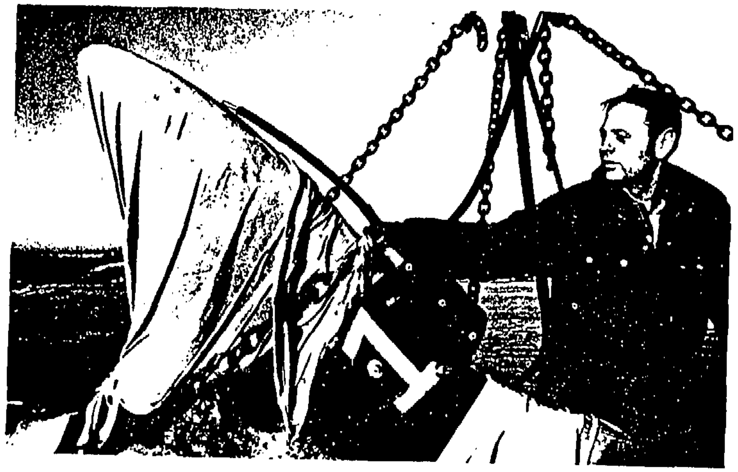

Figure 6. Radio transmitter affixed to female kil ler whale.

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) behavioral observations and (3) pre-tests of the radio trans - mi tters 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, hydrophore recordings of vocal i rations, notations of activities including interactions between the two whales, and responses to such stimuli as changes in the tides or to our activ- ities.

Above all, the instrumented whale was observed closely to ascertain whether the radio-pack appeared to disturb the animal behavioral ly 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 anima 1. 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 re - tained in the San Juan embayment pen included both visual timings of both whales during the daylight hours and radio timings of the in- strumented 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 instnrmentation 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 s tranded 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 catch- ing up process was timed to occur just before high t ide. Surprisingly, the whales exhibited very Little reaction to being caught up except

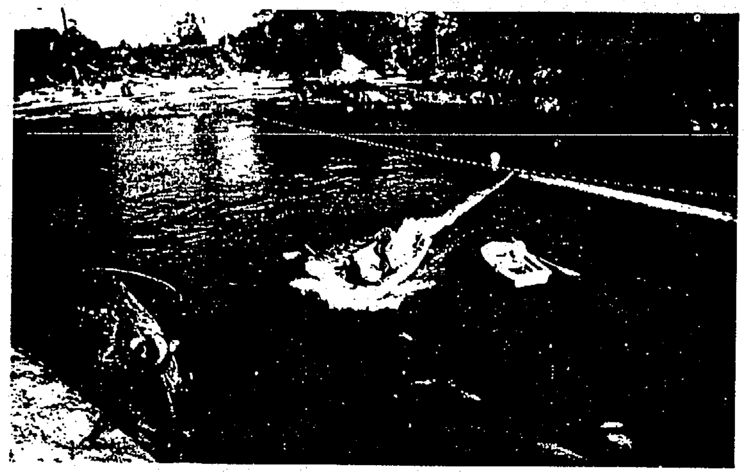

Figure 7. Catching-up the two killer whales in the Kanaka Bay holding pen.

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 bleed 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 reins trumented. 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 ruts (gms)	Location on radio package	Weight after 18 days (gins)	% 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- 32S

[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 x 10 milliamps, K=3.39 x 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 sorer 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 600 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° area surrounding the ship to a distance of approximately five miles. The area of overlap between adj scent antenna arrays was approximately 30°. 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 sets.

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 wade 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 S 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.
s/n	Points along northern edge of Orcas Is land	Shore radio contact.
5/12	Sequim Bay	Observer report.
5/12-5/13	Sequim Bay and immediate off shore waters	Track ing by ship.
5/16	Jervis Inlet, B.C.	Observer report.
7/29	President Channe l opposite Waldron IS land	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	1.6S
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 12s miles north of the most southern sighting of the whales in Sequim BSy, 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.

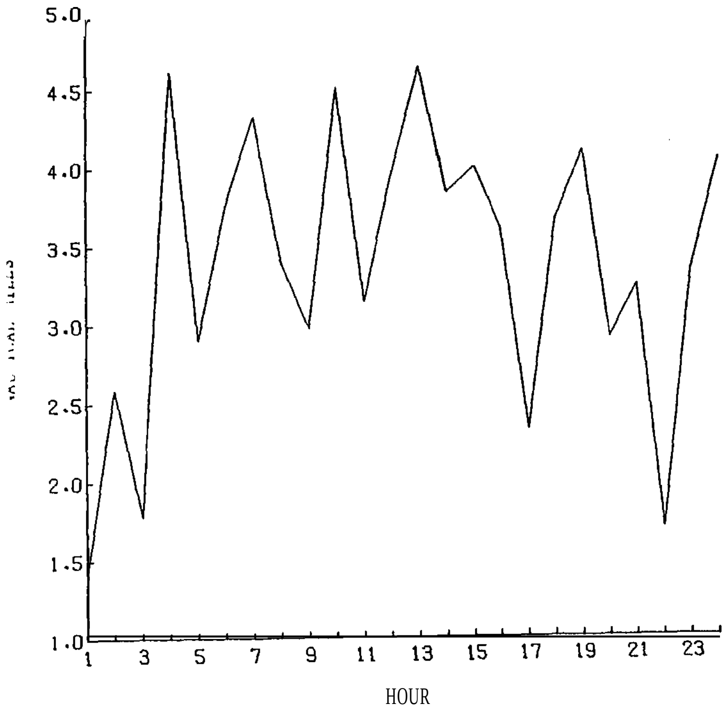

Figure 11. Mean hourly travel distance of the radio-marked killer whales.

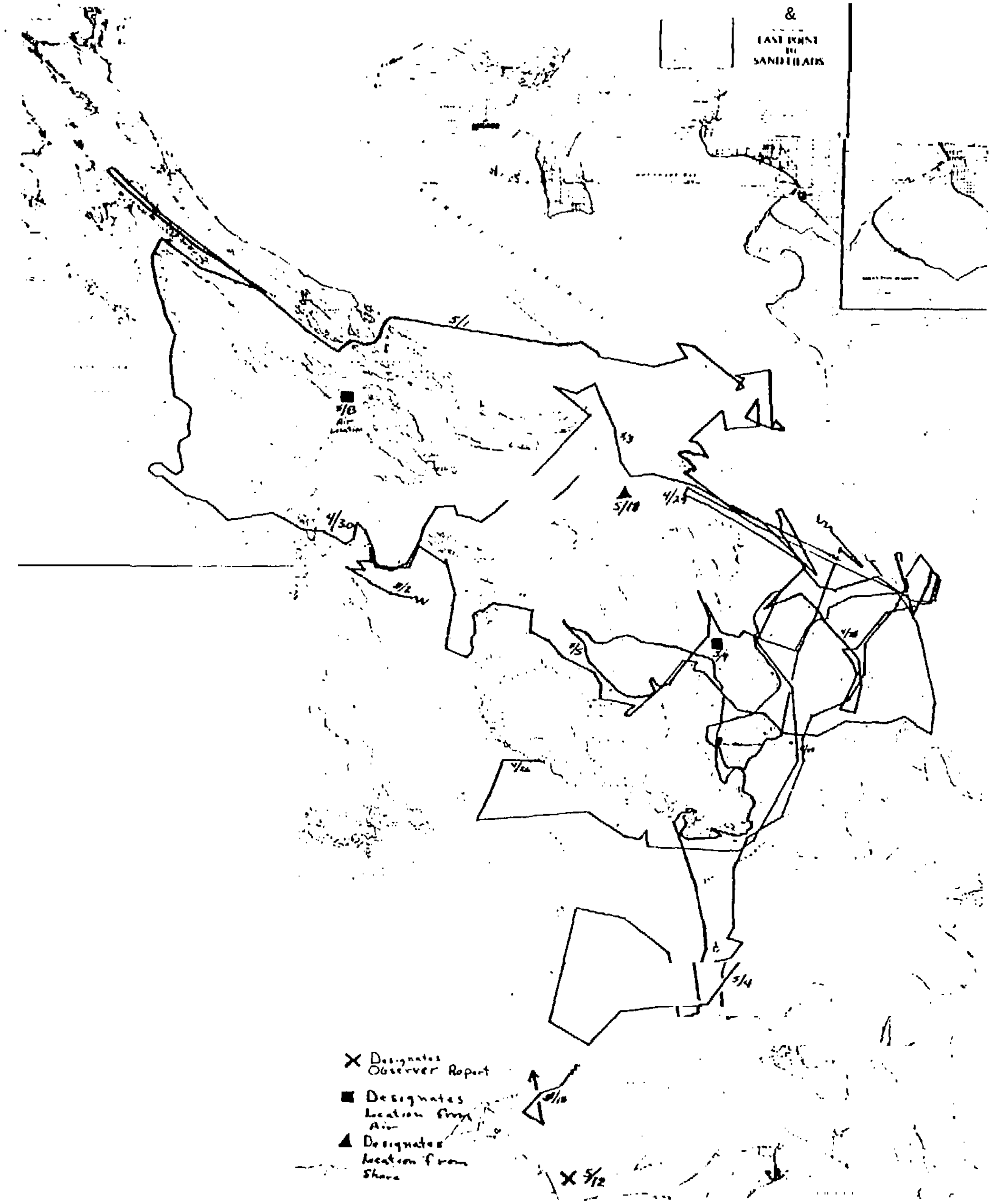

Figure 12. Course of travel of the two radio-marked killer whales duri ng

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

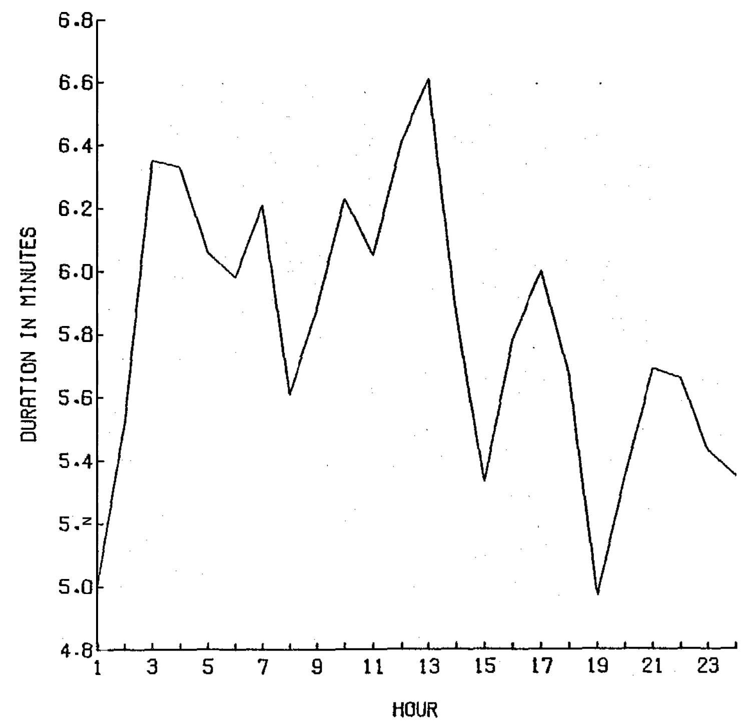

Figure 13. Mean hourly blow-cycle of the radio-marked killer whales.

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, mil 1 ing/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 t rave 1 ing and milling/feeding. This is in marked contrast to the shorter diving durations recorded for the whales when act ively feeding (Figure 13).

The longest dive time recorded for the whales was 17 minutes and less than 20 of the 136S 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 une 22 and again on June 23. On June 22 the whales were intercepted t Sunset Point at the southwest comer of San Juan Island at 1:30 a.m. They were subsequent ly trailed and photographed until :30 in the evening at which time they were in Speiden Channel at he north end of San Juan Island. On June 23 the whales were ntercepted at 12:30 a.m. in President Channel just south of Waldron sland. The whales were subsequently followed unt i 1 7:30 p.m. during hich time they proceeded north through boundary passage and across eorgia Strait to the Pt. Roberts area.

During both encounters extens ive color and black and white holography was taken of the whales. Subsequent analysis of the holographs revealed the compos it *ion* of the two whale assemblages 5 apparently the same. In any event, the whales which *were* readily *lent* i f iable on the basis scars or saddle patch markings were resent in the pod during both of the observation periods.

The number of whales observed during the encounters was ither 16 or 17. Of these, the adult whales were the same animals 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

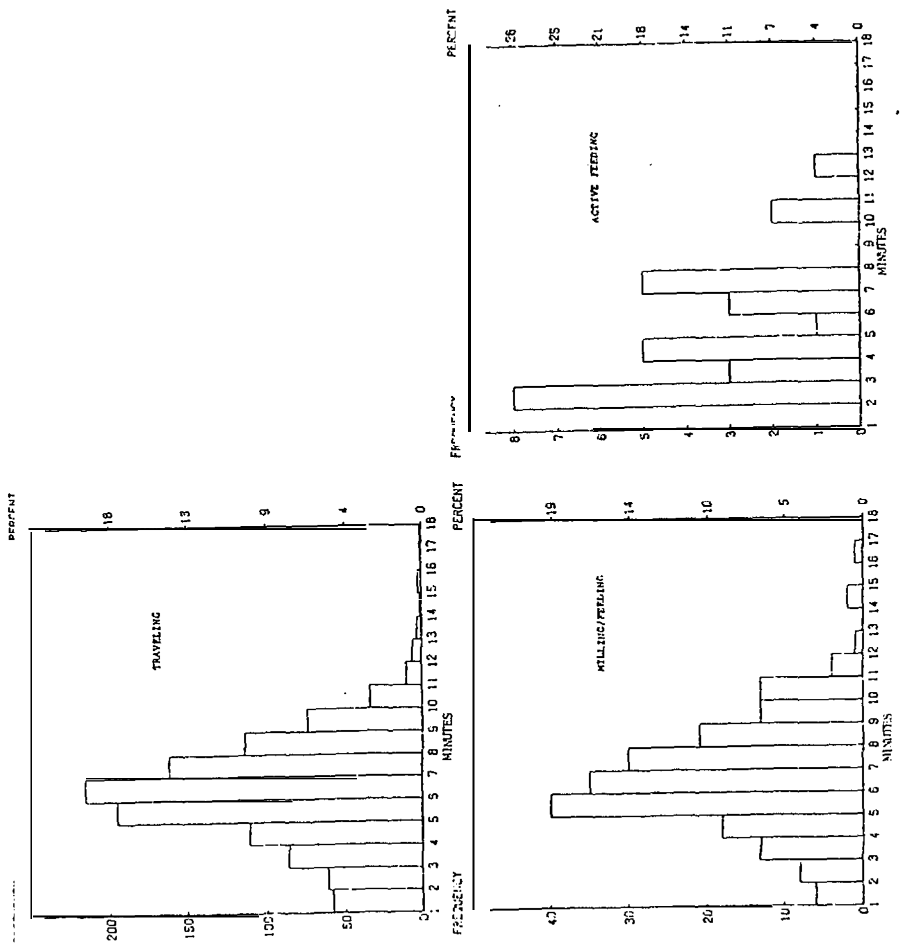

Figure 14. Distribution of blow-cycle durations by type of activity during travel periods.

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 tiles. 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 regularity 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 miniaturization 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 Laboratories 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 paints. 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 miniaturized 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 uniformity 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

UNIVERSI Y OF MINNESOTA
TWIN CITIES

Department of Ecology and Behavioral Biology
108 Zoology Building
Minneapolis, Minnesota S5455
(612)373.5177

October 14, 1976

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

Dear Al:

Were are the specifications on the transmitters --

Frequency: 164 MHZ, *nominal.*	Actual frequencies used:
1) 164.150 MHz	5) 164.500 MHz '
2) 164.225 MHz	6) 164.400 MHz
3) 164.350 MHz	7) 164.400 MHz
4) 164.650 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)
Encapsulant ion compound :	3M Scotchcast #5 electrical resin
An tenna:	Stainless steel 8/32 (7 x 7) vinyl coated . 17" long. Reinforced rubber tubing used co make stand upright.
Power output:	Approximately 10 milliwatt peak

Appendix 1-A

Harness material:	1) Neoprene - impregnated cotton duck 4 ply, 1/8" thick (white material) 2) PVK 120 simple ply polyester/polyvinyl (black material)
Cushion ❑ mterial:	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 1s 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.

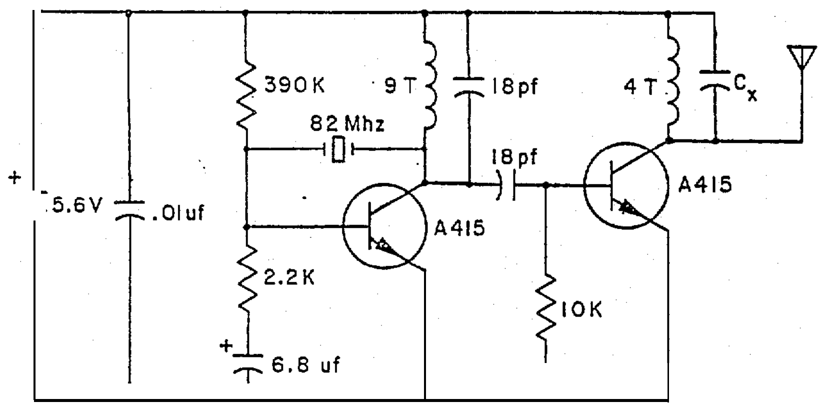
You can describe the harness as you want. Hopefully this fills your needs by way of description.

Sincerely,

Larry Kuechle

LK:gle
Enc.

164Mhz TRANSMITTER



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

MARINE MAMMAL SCIENCE, 1(3): 191-202 (July 1985)

RADIOTAGGING STUDIES OF BELUKHA WHALES (*DELPHINAPTERUS LEUCAS*) IN BRISTOL BAY, ALASKA

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ABSTRACT

Research was conducted in Bristol Bay, Alaska, to determine the applicability of radiotagging to studies of behavior, distribution and movements of belukha whales. Backpack-style VHF transmitters were attached to two belukhas by pinning through the dorsal ridge. Both packages were shed after about 2 wk due to migration of the pin through the tissue. Movements of radio-tagged whales were essentially local within Kvichak Bay. Three basic respiration patterns were identified: surfacings that were grouped into breathing periods separated by longer dives; surfacings that did not occur during restricted breathing periods; and long-m. very-long surfacings separated by shun-m-very-shun dives. These patterns were interpreted as representing traveling, feeding and feeding or resting in very shallow water. Surface and dive interval data were used to calculate a correction factor of .2.75, which could then be applied to aerial survey counts to estimate the total number of belukha whales in the study area. Modifications to radio packages are necessary in order to increase retention time.

Key words: belukha whales, *Delphinapterus leucas*, Alaska, radiotagging, movements, respiration, behavior.

As part of a comprehensive research program on the biology of belukha whales, *Delphinapterus leucas*, in western and northern Alaska (Seaman and Burns 1981, Seaman *et al.* 1982, Frost *et al.* 1984), we investigated the applications of radiotagging. Work was done in inner Bristol Bay, where a large herd of belukha whales occurs every spring and summer, congregated in and near river mouths where prey are abundant. This area also supports the world's largest commercial fishery for red salmon (*Oncorhynchus nerka*). Because of their

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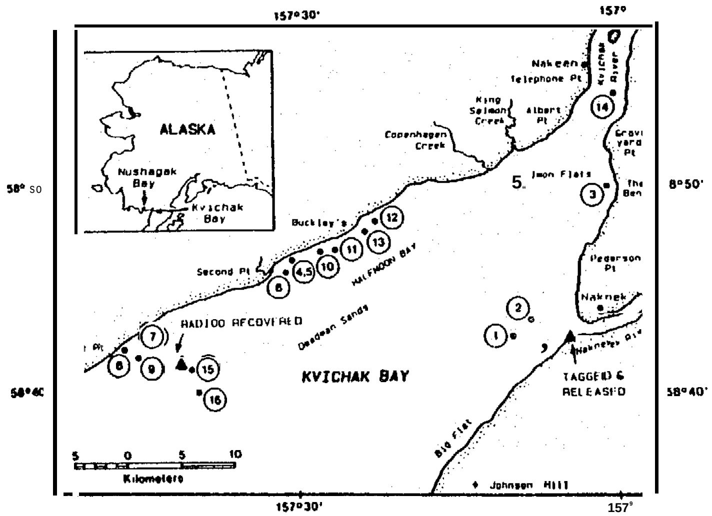

Figure 1. Map of study area in Bristol Bay, Alaska, and locations of the belukha whale BB from tagging at 2145 on 9 June 19"8.3 to recovery of the radio at 1410 on 23 June. I-10 Jun 1630 h; 2-10 Jun 2215 h; 3-1 I Jun 0830 h, 4-11 Jun 1500 h; 5–12 Jun 1150 h; 6–12 Jun 1530 h; 7–13 Jun 1200 h, 8–13 Jun 1625 h; 9–14 Jun 1600/1745 h; 10–16 Jun 1640 h; 11–18 Jun 1000 h; 12–20 Jun 1314 h; 13–20 Jun 1730 h; 14–21 Jun 1157 h; 15-22 Jun 1319 h; 16–22 Jun 1737 h.

interactions with the red salmon fishery, belukhas in Bristol Bay have been comparatively well studied (Brooks 1955, Fish and Vania 197 I).

Kvichak Bay (Fig. 1), where our research was conducted, is characterized by large tidal range (7–8 m), strong currents, very turbid water and extensive mud flats separated by deep channels. Whales appear in this area in April or May shortly after the break-up of seasonal shorefast ice (Frost *et al.* 1984). Other herds of whales appear in spring and summer at a number of locations along the coast from Bristol Bay north and east to the Mackenzie Delta and Amundsen Gulf (Seaman and Burns 198 I). Marking of animals with visual and radio tags will be needed in order to investigate interrelat ionships a mung these grou ps. Our objectives were to evaluate techniques for attaching radio packages and to investigate movements and behavior of whales in Kvichak Bay.

Materials and Methods

We used VHF radio transmitters (type AB 340, Ocean Applied Research Corp., San Diego, CA) with 250-milliwatt power, output at 164.3X7 and 164.585 M Hz, and a 1 00 -millisec transmission repeated 120 times per min.

The transmitter was constructed as a pair of 2 x 15-cm tubes with electronic components in one and lithium batteries in the other. A 47.5-cm semi-rigid whip antenna was attached to the tubing that connected the battery to the electronics. Each radio was shur off by a saltwater switch located near the tip of the antenna and transmitted only when the antenna broke the surface. The transmitter was attached to a fiberglass saddle, 2 l cm long, 12 cm wide and 5 cm high. Total package weight was 450 g. The saddle was molded to fit a cast of a belukha dorsal ridge and was lined with 4-mm-thick open-cell foam. Closed-cell foam was added m the top of the package so that the transmitter would float wirh the antenna nut of the water when it was separated from the animal. The backpack transmitter was similar to that described and used by Gaskin *et al.* (1975) on harbor porpoises (*Phocoena phocoena*) and by Butler and Jennings (I 980) on dolphins (*Stenella* spp.). Packages were attached by inserting a nylon rnd through a hole cored in the dorsal ridge of rhe whale. Magnesium screws were passed through holes in rhe leading edge nf the package and threaded inru either end of the rod. Screws were designed to corrode and release the package after about 6 wk.

The backpack attachment was rested on the carcass nf a recently dead belukha (296.5 cm long) found floating in Nushagak Bay on 29 June 1982. The package fit snugly river the dorsal ridge and, except fur some difficulty in aligning the holes, the attachment was easily accomplished.

We caught whales by herding them with small (4–6 m) motorized boats until the animals stranded themselves in shallow water. This technique used in combination with nets can be very effective for catching belukha whales (e.g., Ray 1962, Sergeant and Brodie 1969). A helicopter was used to locate whales and to coordinate activities hy means of radio contact with the boats. A net 46 m long and 3 m deep, which was constructed of 15-cm stretch-mesh no. 48 thread nylon and hung like a gill net with ncr floats and lead line, was used as a fence to direct or contain the animals. Two pairs of numbered visual streamer rags constructed nf brightly colored polyvinyl chloride fabric and measuring, 4 x 32 cm were attached to each whale by sewing through the dorsal ridge with 1. 5-mm -dia. n ylon-coated stainless steel wire (Sevenstrand Tackle Corp., Huntington Beach, CA).

Radio signals frnm tagged whales were monitored daily, when possible, from shore, boats and a helicopter. The receiving system consisted of a Telonics TR-2 receiver with scanner connected m a two-element YAG I antenna. On the helicopter YAG I antennas were directed outward on each end of a 3-m metal conduit bolted across the nose of the aircraft, and the rwu antennas were connected tu the receiver through a tight-left switch box.

We collected two types of data on rwlio-tagged whales. First, whales were localized by either sweeping the antenna in an arc when working from the shore or boats or switching from left to right antenna in the helicopter and determining the direction of the strongest signal. The signal was then followed toward irs source, usually unt ii a group of whales was sighted. By noting changes in signal strength and in bearing to the signal as the location of the receiver changed, it was usual I y possible to verify the locat ion of the tagged animal.

Verified positions were recorded as relocations of rhat particular whale. Secondly, we recorded data on respiration patterns when we were close enough to the animals to receive clear, strong signals, and when they did not appear m he affected by our activities. All respiration pattern data were recorded from drifting small boats or from shore using hand-held, digital stopwatches. Data collection periods usually lasted 30-40 rein, during which we recorded the length of each surfacing and each dive to the nearest 0.1 sec. The length of a dive is defined as the time from the last audible signal of a series to the reception of the first signal puke upon resurfacing; the duration of continuous signal pulses is considered the length of a surfacing. The surfacing rate is the number of recorded surfacings divided by the length of a data collection period. A breathing period is a series of surfacings separated by dives of less than 30 sec.'

Tagging operations were conducted in Kvichak Bay from 11 May ro 15 July 1983. In addition to radiotagging work, we conducted systematic aerial surveys in Kvichak and Nushagak Bays and recorded opportunistic observations to help describe the distribution, abundance and movements of belukha whales in the area.

RESULTS

The first whale tagged was a 2.3-m subadult dark gray male (referred to as BB), which arrived at the Bumblebee Cannery in South Naknek, Alaska, by truck on 9 June. This whale had been removed from a salmon setnet about 7 km south of the Naknek River mouth and was kept covered and wet until our arrival 2-3 h later. We attached a radio package (164.535 MHz) and two pairs of visual tags, The animal was carried into the water on a stretcher and released. Upon release, the whale swam away in an apparently normal manner and was monitored for 30 min to ensure proper functioning of the radio. Subsequently, verified positions were determined on 16 occasions over a period of 13 days (Fig. I). Signals were routinely detected at more than 20 km (and occasionally up to 30 km) from small boats and at 30-60 km frum the helicopter. BB was visually sighted twice: once from a fixed-wing aircraft on 11 June and once from a small boat on 13 June.

BB's movements were local within Kvichak Bay throughout the two weeks. For at least the first 26 h, he remained near the Naknek River mouth. On 11 June, 36 h after release, he was visually located 14 km to the north. Later that day, BB moved approximately 30 km down the west side of the bay, against a flood tide, in 6 h. During the next 11 days, BB was usually located nearshore within a 30-km stretch of coast from Halfmoon Bay to Lake Point. Between 1730 h on 20 June and about noon on 21 June, he moved 25 km from mid-Halfmoon Bay to north of Graveyard Point. By noon on 22 June, he was near Lake Point, 45 km from his location at noon the previous clay. Several times, BB's subsequent locations were within 1-2 km of each other over 24- and 32-h periods. This whale was last located with radio attached on the 13th day after tagging. On day 14, the radio was found, floating upright and transmitting normally, approximately 3 km northwest of BB's last known location. The

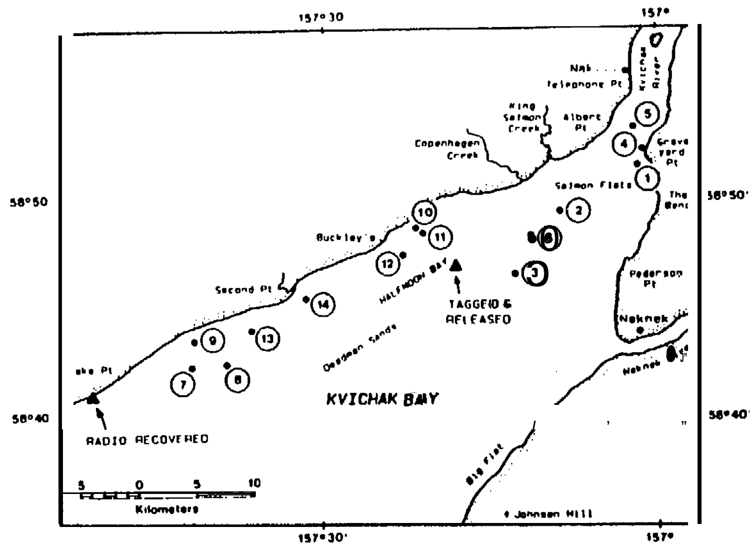

Figure 2. Locations of the belukha whale M from the time of tagging at 1630 on 18 June 1983 to recovery of the radio ar 1500 on 3 July 1983. 1–19 Jun 1800 h; 2–20 Jun 1351 h, 3–20 Jun 1730 h; 4-21 Jun 1157 h; 5–21 Jun 1232 h; 6-22 Jun 1805 h; 7-23 Jun 1405 h; 8-23 Jun 1425 h; 9-23 Jun 1648 h; IO-24 Jun 1339 h; 11–27 Jun 1255 h; 12-27 Jun 1502 h; 13–28 Jun 1110 h; 14–29 Jun 1410 h.

magnesium screws were partially corroded bur intact and still in place in the nylon rod.

On 18 June 1983, a 3.7-m adult white female belukha ("M") was herded into shallow water in Hal fmoon Bay and stranded at slack low tide. After a small net was placed over her head she lay quietly, rising to breathe about once a minute, while a radio package (164.585 MHz) and visual tags were attached. After being tagged and measured, she was guided into deeper water and released. M "s position was determined on 14 occasions over a period of 11 days (Fig. 2). The OAR radio on M, although "identical" to the onc worn by BB, was more difficult to track. Maximum receiving distance was 42 km from the helicopter (signal weak) and 23 km from a small boat. This whale was never visually resighted although her radio signal was repeatedly localized.

After her release, M remained within receiving range for 7 h, then, during a period when respiration data were being collected, she swam out of receiving range to the southwest. She was relocated on the following afternoon in upper Kvichak Bay near Graveyard Point. For the next three days, all locations were in the upper part of the bay. After the fourth day, all verified locations were along the coast between Hal fmoon Bay and Lake Point, Directional information was recorded several times from a receiver located near the mouth of the Naknek

River, which indicated that M made occasional movements between Halfmoon Bay and the Graveyard Point area during this period. Signals from M were last located on the 11th day after tagging. Small boat problems precluded tracking on the 12th and 13th days, and on the 14th day we did not receive a signal despite searching from the Kvichak River mouth to near Lake Point and back. On the 15th day, the radio was found approximately 20 km southwest of M's last known location, lying on its side at the high-tide line with the antenna partially buried in the gravel. Partially corroded screws were still in place in the nylon rod.

Based on locations of successive radio signals, BB made a net movement with a flood tide once, against a flood tide five times and against an ebb tide once. M moved with the flood twice, with the ebb three times and against ebb and flood tides twice each. Visual observations on the direction of movement of groups of belukhas in Kvichak Bay showed that they were moving with the direction of the tide in 77 percent of all observed cases (n = 73, $\bar{x}$ = 20.84, $P < 0.01$). The proportion of observations of whales moving with the flood (37 percent) or with the ebb (63 percent) is in proportion to the total time the tide was flooding (35 percent) or ebbing (65 percent). Of the whales that we observed moving against the tide, only 18 percent moved against a flood, whereas 82 percent moved against an ebb ($\chi^2 = 12.6$, $P < 0.01$). All movements against the tide occurred within 2 h of a tidal change, and 85 percent were within 1.5 h of a change.

We recorded 726 min of surface and dive time data for BB and 224 min for M. Elimination of periods during which signals were weak or possibly not reliable (*e.g.*, shortly after capture and tagging) resulted in usable data for 688 and 142 min. All data were plotted graphically, visually examined, then sorted into groups based on similarities in respiration patterns and comparisons with published information for other species (Leatherwood and Ljungblad 1979, Watson and Gaskin 1983). This included 1,325 surface and dive sequences for BB, and 323 for M. BB's longest recorded dive was 5 min 56 sec, and M's longest was 2 min 8 sec.

For BB, dives were of two basic types: pattern A, in which surfacings were not grouped into breathing periods and pattern B, with surfacings grouped into distinct breathing periods separated by longer dives (Fig. 3). Patterns were further subdivided as follows: A1—surfacings irregular and often widely spaced; A2—surfacings irregular and frequent with few long dives; B1—surfacings clumped into very regular breathing periods; B2—surfacings generally clumped but with some irregularities.

Pattern A was recorded during 41 percent of the usable data collection periods for BB (Table 1). Types A1 and A2 differed in surfacing rates and in relative amounts of time spent at and below the surface: in A1 the mean length of a surfacing was significantly shorter than in type A2 (0.94 *vs.* 1.50 sec; t = 15.06, $P < 0.01$), and the mean length of dive was significantly longer (36.07 *vs.* 19.55 sec; t = 5.59, $P < 0.01$). Pattern B occurred during 59 percent of the data collection periods for BB. Types B1 and B2 did not differ significantly in the mean length of surfacings (1.150 *vs.* 1.151 sec; t = 0.03, $P > 0.90$)

Table 1. Characteristics of the respiration patterns of radio-tagged belukha whales.

Whale	Pattern type (observation time)	Surfacing rate – surfacings per min	Percent time at surface[1]	Percent time diving[2]	Breathing period: Mean number of surfacings	Breathing period: Mean duration (min)[3]	Mean duration of dives (min)[4]	Percent of total observation time
BB	A1 (151 min)	1.62 (n = 244)	2.6	97.4				22
BB	A2 (130 min)	2.86 (n = 370)	7.2	92.8				19
BB	B1 (265 min)	1.77 (n = 470)	3.4	96.6	4.9 (n = 96)	0.73 (n = 96)	2.09 (n = 93)	38
BB	B2 (142 min)	1.70 (n = 241)	3.3	96.7				21
BB	overall (688 min)	1.91 (n = 1,325)	3.8	96.2				
M	A1 (23 min)	1.88 (n = 43)	6.9	93.1				16
M	C (119 min)	2.38 (n = 280)	40.5	[illegible]				84
M	overall (142 min)	2.31 (n = 323)	34.7	65.3				

[1] Includes all periods of time during which signals were received.
[2] Includes all periods of time during which signals were not received.
[3] Includes the period from the start of the first surfacing to the end of the last surfacing including intervening dives of <30 sec.
[4] Includes only those dives between breathing periods, *i.e.*, ≥30 sec in duration.

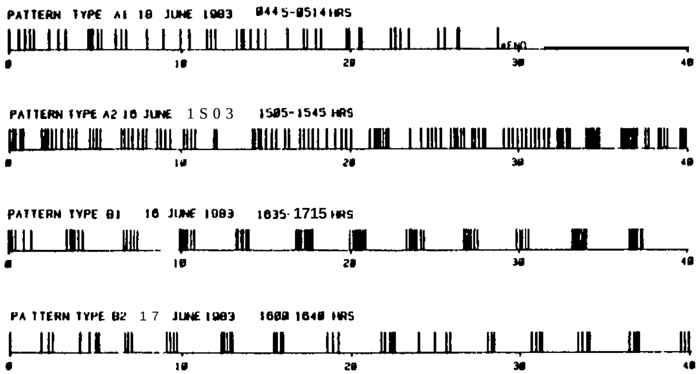

Figure 3. Examples of respiration patterns of the belukha whale BB. Vertical bars indicate periods during which radio signals were received. Scale is in minutes.

or of dives (32.68 *vs.* 34.16 sec; t = 0.41, $P > 0.50$), and the number of surfacings per min and proportions of time spent at the surface were also similar. The only difference between these patterns was a higher incidence of single surfacings during type B2. In pattern B1 the respiration sequence consisted of a breathing period averaging 4.9 rolls (range 1–8), separated by dives lasting about 10 sec, followed by a longer dive which lasted an average of 2 min 5 sec (range 1 min 35 sec to 3 min 48 sec).

Two dive patterns were recorded for M: one corresponding to A 1, and a second, type C, in which long-to-very-long surfacings alternated with short-to-very-short dives (Fig. 4). Type B dives were identified during radio tracking of M, but were not encountered during periods when we collected respiration data. Of the usable surface and dive time data for M, 16 percent was classified as type A 1 (Table I). The surfacing rate was similar to A 1 for BB; however, the proportion of time spent on the surface by M was more than twice that by BB, largely due to a significantly greater average length of surfacing (2.22 sec for M *vs.* 0.94 sec for BB; t = 10.62, $P < 0.01$). The average lengths of type A 1 dives for BB (36.07 sec) and M (29.78 sec) were not significantly different (t = 0.89, $P > 0.30$). Pattern C for M was unlike all others and differed most notably in that signals were received during 40 percent of the data collection periods,

Discussion

Belukha whales are concentrated in the middle and upper portions of Kvichak and Nushagak Bays from at least mid-May through July. Brooks (1955) postulated a seasonal movement from Kvichak Bay to Nushagak Bay caused by changing abundances of prey (salmon), and Lensink (1961) stated that movements between the two bays are common. Nonetheless, we know of no

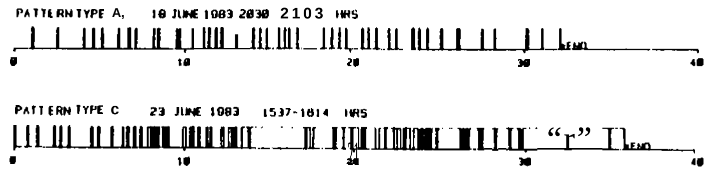

Figure 4. Examples of respiration patterns of the belukha whale M. Vertical bars indicate periods during which radio signals were received. Scale is in minutes.

direct information to support this assertion. In 1959 and 1960, Lensink applied visual tags to 46 belukhas in Kvichak Bay. Two animals were located 1–3 months after tagging, both in Kvichak Bay. During the 2-wk periods in which we followed radio-tagged belukhas in 1983, their movements also appeared to be confined to Kvichak Bay. We flew nine aerial surveys between 15 April and 14 August 1983 and sighted belukhas in areas intermediate between Kvichak and Nushagak Bays on four occasions: 15 April, 5 May, 14 June and 24 July. The June sightings were of fewer than 10 whales whereas those in April and May were of 40 or more, all headed into Kvichak Bay. Observations in both 1982 and 1983 indicated a clear trend of increasing abundance in Nushagak Bay from June to mid-July, but showed no obvious concurrent decrease in Kvichak Bay (Frost *et al.* 1984). We consider it very likely that belukhas do move between Nushagak and Kvichak Bays (about 80 km apart) since we have regularly recorded daily movements of 100-150 km within Kvichak Bay.

The two radio-tagged belukhas made substantial movements up and down Kvichak Bay, but were sometimes located in the same area over periods of several days. Successive locations of tagged animals showed no clear trend of net movement in relation to tidal cycles. However, interpretation of movements from these data is difficult because verified locations were usually several hours apart, often involving a change of tide. Observations from small boats and aircraft indicated that belukhas in Kvichak Bay moved between the Kvichak River mouth and the tidal flats of the outer bay on a fairly regular twice-daily basis (Frost *et al.* 1984) and it is likely that the tagged whales did the same. These movements were usually with the tide. Occasional movements against the tide (predominantly ebbing tides) served to keep the whales in the same general area from day to day. Brooks (1954) and Lensink (1961) also found that belukhas generally swam up the Kvichak River on flooding tides and down on the ebb. Our observations and those of Fried *et al.* (1979) have indicated that belukha movements in Nushagak Bay were independent of tidal stage. We have no explanation for the apparently different movement patterns in the two adjacent bays. It is probable that the overall pattern of movements and utilization of various areas is influenced largely by the distribution and movements of prey (Frost *et al.* 1984).

Without visual confirmation, correlation of behaviors with respiration patterns of radio-tagged whales is difficult. Pattern B, with surfacings clumped into discrete breathing periods separated by relatively long dives, was interpreted as feeding in harbor porpoises (Watson and Gaskin 1983) and in spotted dolphins, *Stenella attenuata* (Leatherwood and Ljungblad 1979). Characteristics of breathing and diving periods for the whale BB were similar to those for harbor porpoises, but the belukha had a longer mean diving period (2.09 *vs.* 1.44 min). BB's average breathing period (0.73 min) was about one-third the length of the diving period, which suggests that belukhas may be somewhat better divers than harbor porpoises, in which breathing periods were one-half as long as dives (Watson and Gaskin 1983). Although the longest dive recorded for BB (5 min 56 sec) was almost 2 min longer than that reported for harbor porpoises (4 min 4 sec), the maximum to mean dive ratio of 2.8 was identical for the two species. This agrees with the suggestion by Watson and Gaskin, based on data for harbor porpoises and killer whales, *Orcinus orca*, that there might be a consistent maximum to mean dive ratio in odontocetes.

Pattern A for belukhas resembles patterns associated with traveling in *Phocoena* and *Stenella*. Leatherwood and Ljungblad (1979) associated frequent surfacings in *Stenella* with "running" and periods of less frequent surfacings with "traveling or exploratory diving." Watson and Gaskin (1983) reported a higher surfacing frequency in harbor porpoises trapped in weirs or carrying radio transmitters compared to other free-ranging animals. We suggest that patterns A1 and A2 for belukhas may represent traveling with *vs.* against the current. On 28 June, M exhibited dive pattern A1 as she left an area where she had apparently been finding for several hours and traveled steadily north, with the tide, until she was out of range of the receiver.

Respiration pattern C was characterized by very long periods of continuous signals with irregular interruptions. When the signal was tracked toward its source, we located a group of whales in water slightly more than a meter deep. The radio-tagged whale was not seen, but the signals stopped as the whales moved rapidly to deeper water. We interpret this pattern as indicative of whales feeding or resting in very shallow water.

Surface-to-dive time ratio is important in determining the number of whales in an area since, in very turbid waters such as Kvichak Bay, belukhas are visible only when their bodies break the surface. If one were to estimate abundance of a group of whales in a photograph based on the overall proportion of time BB spent at the surface (3,8 percent) it would be necessary to multiply the counts from the photo by 26 to estimate the total number of whales present. However, when whales are counted from a survey aircraft, the view is not instantaneous and correction factors must be calculated based on the length of time an area is scanned as well as the length of surfacings and dives (Davis *et al.* 1982). The probability that a whale will be at the surface where it can be seen is equal to the mean length of a surfacing plus the length of time an area is within the field of view, divided by mean length of a surfacing plus the mean length of a dive. The correction factor by which aerial survey counts can be multiplied to derive the actual abundance of whales is the reciprocal of this probability. Using all surface and dive time data from BB and type A 1 data for M, the mean correction factor for surveys flown at 165 km/h (viewing time 10 sec, altitude 300 m) is 2,75. We made a comparison of simultaneous aerial and

boat counts, which suggested a multiplier of 2,4 to 2,8. These are similar to the correction factor used by Sergeant (1973), who estimated that in turbid waters of western Hudson Bay belukhas were visible at the surface about one-third of the time. Fraker (1980), working in turbid waters of the Mackenzie estuary, proposed a correction factor of 2, and also noted that neonates and dark-colored juveniles were generally not visible at altitudes of 300 m and more. Brodie (1971) used a correction factor (excluding neonates and yearlings) of 1,4 for belukhas in Cumberland Sound; however, the water there is clear and the whales are visible below the surface.

Our results indicate that it is feasible to radio-tag and relocate free-ranging belukha whales. The whales showed no apparent reaction to being tagged and subsequently appeared to behave normally. The packages came off the whales after approximately two weeks, and there was no evidence of attempts at removal by the whales. We assume that hydrodynamic drag on the packages caused the nylon rods to migrate through the hide and blubber. Irvine *et al.* (1982) applied similar radio packages to dorsal fins of bottlenose dolphins, *Tursiops truncatus*, and noted problems with migration of bolts through the tissue, which resulted in a maximum tracking period of 22 days. Read and Gaskin (pers. commun.) had similar problems with bolting radio packages to harbor porpoises. Although belukhas have thicker skins than porpoises and dolphins (Sergeant and Brodie 1969), the radio packages we applied were also shed quite quickly despite a triangular cross-sectional area of tissue above the bolt of 4.5 x 1.5 cm. There appeared to be no difference in duration of attachment between the subadult and adult belukha.

Retention time of the bolt-through style radio packages would probably be increased by reducing drag through elimination of the foam flotation, thereby sacrificing recoverability, and by the use of two attachment pins. We expect such modifications might increase attachment duration to one or two months; however, long-term retention will require development of a tag with more anchoring points and perhaps the coating of attachment surfaces with a bio-compatible substance.

Acknowledgments

This study was supported by the U.S. Department of the Interior, Minerals Management Service, through the Outer Continental Shelf Environmental Assessment Program, and by the Alaska Department of Fish and Game. We especially thank Ken Taylor, Dick Sellers and Mark McNay for their assistance during field work. John Hall, Bruce Mare and Ned Manning helped with development of radio-tags. Lanny Cornell provided a cast of a belukha dorsal ridge and allowed us to test a radio package on a captive belukha. We thank the anonymous reviewers for their helpful comments and suggestions. Graphics and computer analyses were done by Jesse Venable, and the manuscript was typed by Dawn Hoover.

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RADIO TRACKING THE MOVEMENTS AND ACTIVITIES OF HARBOR PORPOISES, *PHOCOENA PHOCOENA* (L.), IN THE BAY OF FUNDY, CANADA

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ABSTRACT

Eight harbor porpoises were radio tagged (172173MHz) and released in the western Bay of Fundy between August 1981 and August 1983 The duration of contact with radio-tagged animals ranged from 0.3 to 22 4 days 11,,,. 1,.,1,,,, porpoise was tracked for 22 4 days and utilized a home range area of 210 km^2 In all observed cases, the movement of radio tagged porpoises coincided with the direction of tidal flow in the major channels and passages of the region Analysis of 39 2 hours of ventilation sequences revealed that radio tagged porpoises were relatively inactive from midnight until 0600 and more active during other periods

This report documents the results of a study on the movements and activities of radio-tagged harbor porpoises, *Phocoena phocoena*, in the Bay of Fundy, Canada. The primary objective of this research was to determine the home ranges of individual harbor porpoises during the summer months. The study also provided insights into the behavior and activities of radio tagged animals.

Studies of cetacean home ranges often rely on resightings of tagged or naturally marked animals (Irvin. et al. 1981; Bigg 1982; Dorsey 1983). These methods are of limited value if individual animals travel outside the area under observation and may result in underestimation of the utilized range. A more effective means of estimating home range area is to monitor the movements of radio tagged individuals (McDonald et al. 1979). Several recent studies have successfully employed radio-tracking techniques in field studies of cetacean species (see review by Leatherwood and Evans 1979). Notable among these are investigations of *Delphinus delphis* by Evans (1971), of *Tursiops truncatus* by Irvine et al. (1981), and of *Lagenorhynchus obscurus* by Würsig (1982)

In a preliminary study of harbor porpoise movements (Gaskin et al. 1975), we demonstrated that radio tracking techniques could be successfully applied to this species. Although this initial research was promising, we felt that the transmitters available at that time were too large to be carried by these small porpoises (see Watson and Gaskin 1983). The recent development of smaller transmitters and the continuing availability of live porpoises from herring weirs (Smith et al. 1983) have enabled us to undertake the present study.

METHODS

The study area encompases Passamaquoddy Bay, the channels and passages around Deer Island, and waters further offshore to Grand Manan Island (Fig. 1). During the summer, mean monthly water temperatures for the upper 25 m of the water column range from 6.4° in June to 11.0°C in September (Bailey et al. 1954). The oceanography of the region is dominated by large semidiurnal tides, which have a mean amplitude of 5.5 m at North Head, Grand Manan (Anonymous 1982). The large tides generate strong currents, with velocities reaching a maximum of 2 4 m/s in Letite Passage (Forrester 1960). Further information regarding the oceanography of the region may be found in Smith et al. (1984).

Harbor porpoises were seined from herring weirs (Smith et al, 1983), placed on a sheet of open cell foam, sexed, and measured. The porpoises were liberally sprinkled with seawater throughout the tagging procedure to prevent overheating. Two 0.64 cm diameter holes were bored through the dorsal fin with a laboratory cork borer, cleansed in alcohol prior to use. The holes were immediately cold-cauterized with a histological freezing spray.

Transmitters were attached to the dorsal fin with two 0.64 cm diameter stainless steel bolts, each covered with a thin sleeve of teflon (see Figure 2). A thin, neoprene-lined plastic plate was placed between the transmitter and dorsal fin and an identical plate was positioned on the opposite side of the

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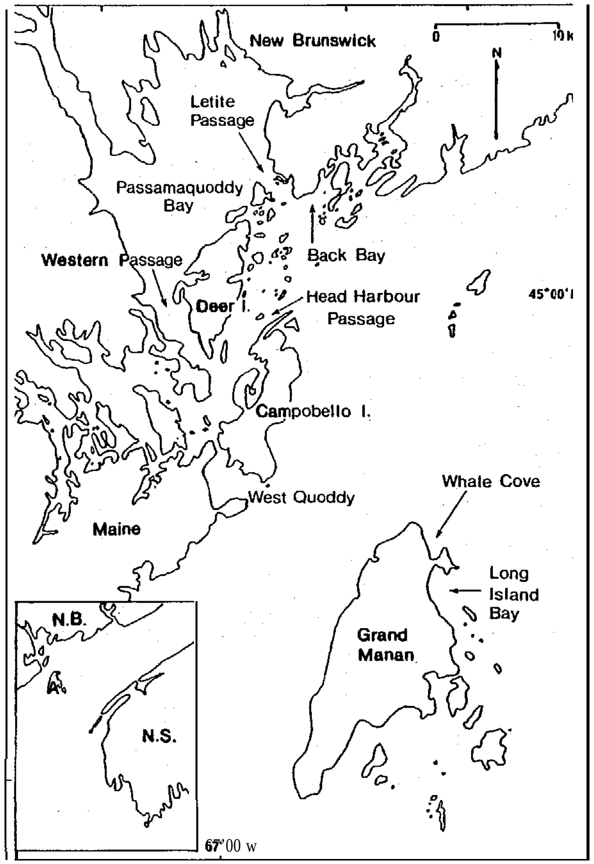


FIGURE 1.–The harbor porpoise study area with place names mentioned in text. The inset shows the study area in relation to the rest of the Bay of Fundy.

fin. The teflon-covered bolts, passed through the transmitter and plastic plates, were fastened with corrodible, low grade steel nuts.

The radio transmitters measured 3.2 x 3.8 x 6.0 cm and weighed about 170 g in air (Model A-A Telonics,[2] Mesa, AZ). The transmitting antennae consisted of 43 cm semiflexible whips, designed specifically for use with marine mammals.

Transmitted VHF signals (172-173 MHz) consisted

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

of 20.00 ms pulses at intervals of 0.4s. Lithium batteries provided a maximum power output of 0.75 mW and an expected transmitting life of 1.6-6.0 mo. The maximum transmitting range across open water was about 15-20 km.

We used a Telonics TR-2 telemetry receiver with a two-element, hand-held directional antenna. The approximate direction of the transmitter was determined by rotating the antenna and noting the strongest signal. A digital data processor (Telonics TDP-2) provided a visual display of signal strength.

The position of a tagged porpoise was determined either by tracking the animal until visual contact was established, or by triangulation from shore. In the latter method, the receiving system was moved along the shore, and signal bearings at two or more locations were noted. The intersection point of these bearings was then used to approximate the position

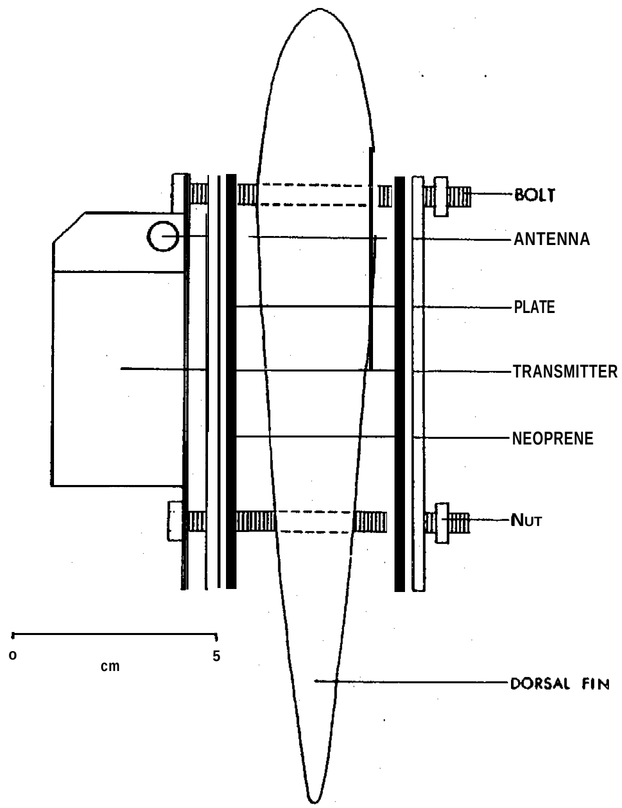


FIGURE 2.–The transmitter package used in radio-tracking studies of harbor porpoises in the Bay of Fundy. The bolts attaching the transmitter to the dorsal fin were covered by thin teflon sleeves.

of the porpoise. To ensure bearing accuracy, a series of readings were taken at each location, and the average used in triangulation (Springer 1979). Each sighting or radio location was assigned to a 1 km grid square of the Universal Transverse Mercator System. Derived radio locations were discarded if the triangulation could not place a porpoise within a 1 km square; the time elapsed between fixes and bearing error (± 5°) precluded more precise estimation. Positional data were collected at least once a day, but usually on a more frequent basis.

The radio signal was received only when the transmitting antenna was exposed, allowing the duration of both submergence and surface periods to be recorded. Such ventilation data were collected on an opportunistic basis throughout the tracking period of each porpoise.

A detailed analysis of the methods used in this study is presented in Read and Gaskin (1983).

RESULTS

Movements

Eight harbor porpoises were released carrying transmitters over the course of the study (Table 1). During the attachment procedure, porpoises wore out of the water for a mean of 6.6 min (SD ± 1.4, n. 8), during which lime most animals remained fairly still Only two porpoises exhibited any trauma while being handled; RT-5 vomited briefly, and RT-7 (a 110 cm calf) repeatedly lashed its flukes. The latter porpoise appeared momentarily disoriented when returned to the water, but quickly resumed swimming and surfacing normally after being joined by a larger porpoise. The larger animal, presumably the calf's mother, had also been trapped in the weir, but escaped overnight and remained in the vicinity until the ca lf's release.

Duration of radio contact ranged from 0.30 (RT-5) to 22 .4 d (RT-2), with a mean of 5.1 d (SD ± 7.1, n. 8) In some instances, loss of radio contact may

TABLE 1.—Data sum mary for harbor porpoises radio-tagged and released In the western Bay of Fundy

Porpoise code	Length (cm)	Sex	Frequency (MHz)	Date of Release	Duration of contact (d)
RT 1	132	M	173350	050001	305
RT-2	119	M	173550	200881	224
RT 3	145	M	173500	290782	532
RT-4	131	F	173 100	310882	316
RT-5	114	M	173000	310002	030
RT-6	116	M	173700	010982	2,72
RT 7	110	M	173650	030902	1 83
RT-8	114	M	172600	090883	225

have been due to the premature release of the transmitter package. The rear bolt attaching the transmitter to the dorsal fin of RT-3 was missing when the porpoise was photographed 5 h before signal loss occurred. The radio signals of RT-3 and RT-7 were being monitored when contact was lost, and in both cases termination of the signal was abrupt, a pattern compatible with the hypothesis of transmitter loss. In our limited observations of radio-tagged porpoises (see below), we did not see any evidence of displacement of the transmitter package (Irvine et al. 1982).

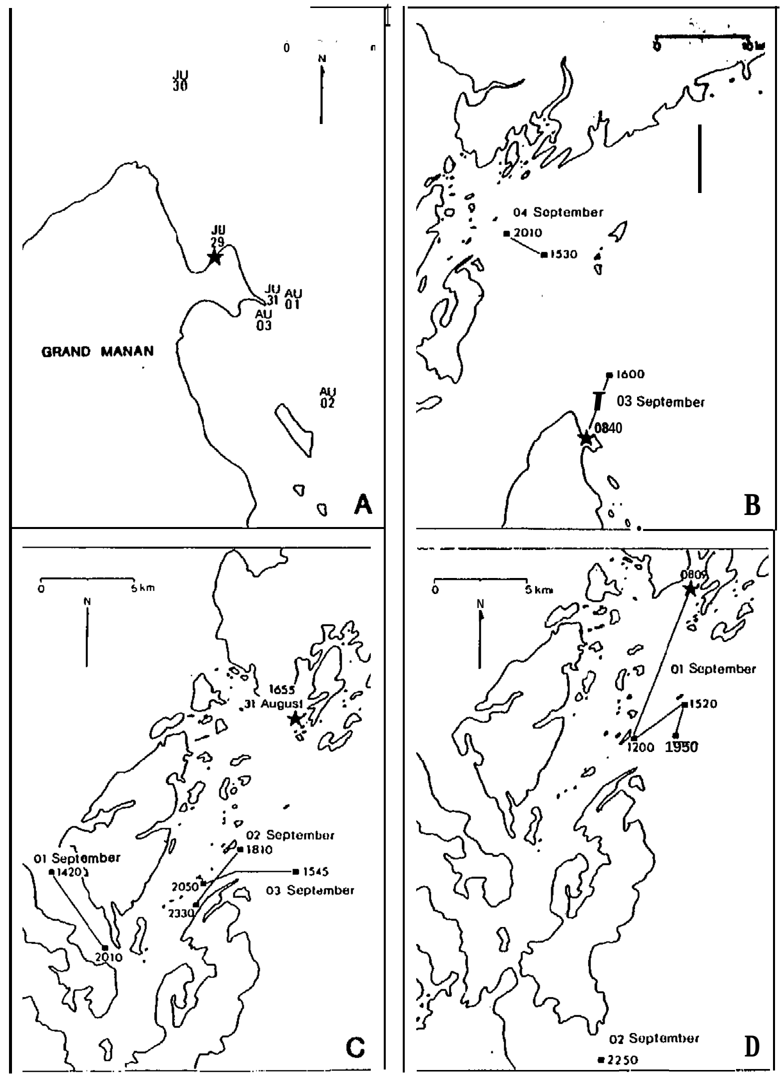
Over the course of the study, three porpoises were released from the same weir in Whale Cove, Grand Manan. Attempts to relocate RT-1, the first porpoise released in Whale Cove, were frustrated by fog and heavy seas which persisted for the entire 3-d tracking period. In addition, the shoreline configuration of northern Grand Manan prevented accurate triangulation. However, the strength and direction of the signal received from shore indicated that the porpoise remained in the vicinity of northern Grand Manan until signal loss occurred. The movements of the other two porpoises released in Whale Cove (RT 3 and RT-7) are illustrated in Figure 3A and B.

On 30 August 1982, four porpoises were reported trapped in a weir in Back Bay, mainland New Brunswick. A female (RT-4), accompanied by a 101 cm calf, and a young male (RT-5) were released on 31 August. The remaining porpoise, another young male (RT-6), was tagged and released the following day. RT-4 and RT-5 remained together for at least 7 h, after which contact was lost with RT-5. The movements of RT-4 and RT-6 are depicted in Figure 3C and D.

The longest tracking sequence recorded in this study was that of RT-2, released near St. Andrews, mainland New Brunswick. This porpoise spent the majority of its 22-d tracking period within Passamaquoddy Bay, although occasional excursions were made to the east of Deer Island (Fig. 4). The home range of RT 2, calculated using the convex polygon method, was about 210 km² (excluding land masses).

RT-8, the only porpoise to be radio-tagged in 1983, travelled from its release point m northern Passamaquoddy tiny to West Quoddy in shout 48 h. Logistical constraints prevented more precise determination of the movements of this animal.

FIGURE 3 Movements and positions of radio tagged harbor porpoises in the Bay of Fundy The ,,4,.:,, ,.,, nt of each porpoise is indicated by a star A) Position of porpoise RT 3 at 1200 of each day of tracking period; B) Movements of porpoise RT 7; C) Movements of porpoise RT-4. D) Movements of porpoise RT-6



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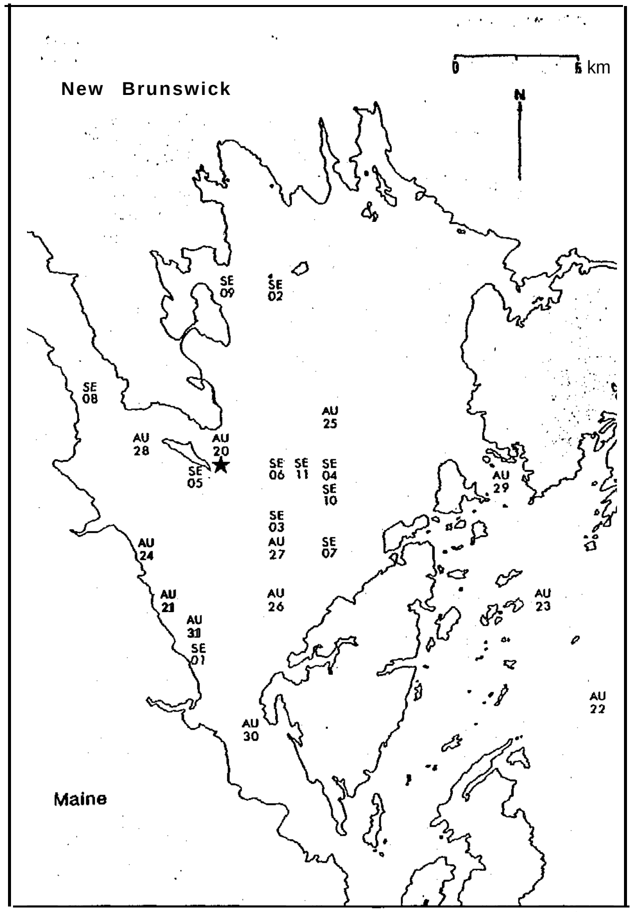

FIGURE 4.—Position of porpoise RT-2 at 1200 of each day of tracking period in the western Bay of Fundy.

The movements of three radio-tagged porpoises (RT-2, RT-4, RT-6) were tracked through the major passages around Deer Island on seven occasions. In all cases, the direction of movement coincided with the direction of tidal flow. The strong correlation between porpoise movements and current direction in these areas was demonstrated on 30 August 1981, when RT-2 moved up Western Passage with the flood tide, turned at slack high water and moved out with the ebb.

Two radio-tagged porpoises were resighted on several occasions. RT-2 was observed resting at the surface in the approaches to Head Harbour Passage on 22 August 1981. Although the porpoise was alone, several groups of resting animals were present in the vicinity. RT-3 was resighted on six occasions; during five of these sightings the radio-tagged animal was accompanied by a single large porpoise. These observations gave no indication that the transmitter packages affected the behavior of tagged porpoises.

Attempts to relocate radio-tagged animals demonstrated some of the inherent problems involved in censusing harbor porpoise populations. Even with the aid of directional receivers and brightly painted transmitters, it was difficult to sight a tagged porpoise or to follow its movements after it had been located. It proved particularly difficult to see radio-tagged porpoises while they lay motionless at the surface.

Patterns of Activity

In total, 39.2 h of ventilation sequences were recorded from four radio-tagged porpoises (RT-2, RT-3, RT-4, RT-7). These sequences comprised 4,680 individual dives, lasting from 2 to 195 s.

Two types of signals were received from radio-tagged animals. The most common signal was brief (1-3 s) and indicated that the porpoise had surfaced and submerged in a continuous motion. Such action patterns are commonly referred to as rolls (Amundin 1974; Smith et al. 1976). Other signals were more prolonged (4-100 s) and are referred to here as surface periods.

Prolonged signals received from radio-tagged harbor porpoises have previously been interpreted as near-surface swimming (Gaskin et al. 1975). However, visual observations of radio-tagged animals RT-2 and RT-3 indicated that such signals originated from porpoises resting motionless at the surface. The strength of the transmitted signal attenuated rapidly as the length of exposed antenna decreased, making it unlikely that signals could be received at any distance from porpoises swimming just below the surface (see also Frost et al.[3]).

Radio-tagged porpoises exhibited two readily discernible activity states (Fig. 5). Low activity (or relative inactivity) was characterized by frequent surface resting periods interspersed with rolls; resting periods accounted for over 55% of all signals in this activity state. Porpoises were considered active (high activity) when resting periods were absent or infrequently recorded. It is important to note that porpoises did not rest at the surface when wave height was >30 cm and winds speeds exceeded 13 km/h (see also Dudok van Heel 1962, Andersen and Dziedzic 1964).

[3]Frost, K. J., L. F. Lowry, and R. R. Nelson. 1983. Investigations of belukha whales in coastal waters of western and northern Alaska, 1982-1983 marking and tracking of whales in Bristol Bay. Final Report, Contract NA 81 RAC 00049, 104 p.

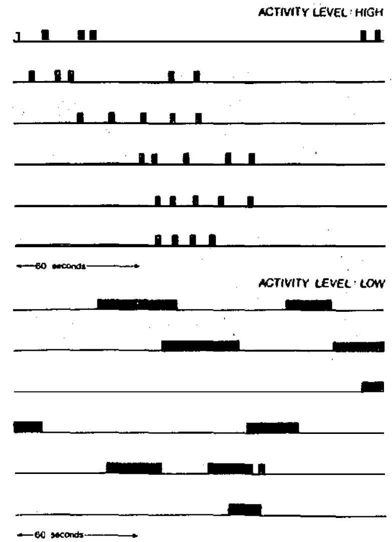

FIGURE 5.—Examples of signal patterns used to derive activity states of radio-tagged harbor porpoises (each example represents a continuous record). Activity level was considered high when signals were dominated by rolls (signal duration 1-3 s). Activity level was considered low when signals were dominated by surface resting intervals (signal duration >3 s). The signal pattern used to demonstrate the high activity level (top) is characteristic of Pattern B respiration (Watson and Gaskin 1983).

Radio-tagged porpoises exhibiting the high activity state expressed two ventilation patterns; these are described using the terminology of Watson and Gaskin (1983). Most data recorded in this activity state consisted of Pattern B, a series of long dives, each followed by a sequence of several rolls (see Figure 5). Less commonly observed was Pattern A, in which single rolls followed relatively short submergences (seldom exceeding 3(J s in duration), Pattern A was exhibited for brief periods only (5.16 min) and comprised <4% of all signals recorded during high activity sequences.

Ventilation data recorded from RT-2 and RT-4 were dominated by low activity sequences. However, low activity sequences were not recorded from either RT-3 or RT-7. Although RT-3 was frequently observed resting at the surface, the loose transmitter package (see shove) caused the antenna to reflect backwards, allowing signal reception only during rolls. Thus, it was not possible to accurately monitor the duration of resting periods for this porpoise Data from RT-7 were acquired only during periods of high winds and heavy seas which precluded surface resting behavior.

Because surface resting was the criterion on which determinations of activity levels were based, it was impossible to ascertain the activity level of radio-tagged porpoises in periods of high winds and heavy seas. To construct an activity budget, theref ore, it was necessa ry to exclude data recorded during periods when surface resting was not possible. A total of 10.5 h of ventilation sequences were recorded under such conditions, In addition, data acquired from RT-3 were excluded because of the bias imposed hy the transmitting system. After these data had been deleted, 24.5 h of vent.iktion sequences recorded from RT-2 and RT-4 remained,

Both RT-2 and RT-4 were relatively inactive from midnight until 0600, spending over 90% of this period in the low activity state. Both porpoises spent a considerable portion of this time resting at the surface (Table '2). During this period of reduced activity, the porpoises were seldom located in nearshore areas, although they frequented such areas during other periods. The two porpoises were highly active for 35% (RT-2) and 36% (RT 4) of daylight and evening hours (0600" until midnight) (Table 2).

DISCUSSION

Movements and Ranges

Radio-tagged harbor porpoises demonstrated considerable mobility within the study area, often moving distances of 15-20 km in a 24 h period. These results are similar to those previously reported from radio-tagged harbor porpoises in the region (Gaskin et al. 1975). Other inshore odontocete species exhibit daily movements of a similar magnitude. For exam pk; dusky dolphins, *Lagenorhynchus obscurus*, tracked by Würsig (1982), travelled a "mean minimum distance" of 19.2 km each day. However, pelagic species apparently travel over much greater distances, A pelagic spotted dolphin, *Stenella attenuata*, tracked by Leatherwood and Ljungblad (1979), travelled over 100 km in a I 2-h period, while common dolphins, *Delph in us delphis*, may cover distances of 70-140 km each day (Evans 1°7 1).

The mobility exhibited by the majority of radio-tagged porpoises suggest that the ranges of these animals were similar to that calculated for RT-2 (2] O km²). Only one other study has examined the areas of home ranges utilized by odontocete cetaceans. Wells et al. (1980) used resightings of naturally marked animals to estimate the size of bottlenose dolphin, *Tursiops truncatus*, ranges in the coastal waters of western Florida. The mean home ranges of these dolphins varied with age and sex, and ranged from 15 to 41 km². It is possible that the apparent difference in the size of home ranges of these two species reflects the exploitation of different prey species. In the Bay of Fundy, harbor porpoises feed predominantly on juvenile herring, *Clupea harengus* (Smith and Gaskin 1974), which exhibit a high degree of mobility (Jovellanos and Gaskin 1983). 1 n contrast, Florida bottlenose dolphins are opportunistic predators on species such as mullet *Mugil cephalus*, which may be more sedentary in nature (Irvine et al. 1981).

Patterns of Activity

The patterns of activity observed in the present

TABLE 2 –Activity patterns of radio tagged harbor porpoises RT-2 and RT-4 in the western Bay of F undy T he low activity state was characterized by frequent surface resting periods, winch were infrequent or absent m the high a ctivity state Only data recorded during calm conditions have been included

Porpoise	Time	Observation time (mm)	Activity high (oh)	Activity low (%)	At surface (%)
RT-2	0000-0559	352.9	20	98 0	314
	06001159	2?4 8	149	851	18.8
	1200-! 759	4352	46.0	540	112
	18002359	1652	41 0	59.0	122
Total		1,2205	257	743	100
RT-4	0000.0559	116 0	7 0	93.0	18.5
	0600-1159	370	1000	00	00
	12001759	0 0	--		—
	1800-2359	907	9 9	901	136
Total		243 7	222	77 8	13 9

study do not support previous contentions that the metabolic require ments of harbor porpoises (see Kanwisher and Sundnes 1965) are such that individuals must speed a large proportion of each day e ngaged in foraging behav ior (Smith and Gaskin 1 974; Watson and Gaskin 1983).

Herbers (1981) has hypothesized that behavioral inactivity is a product of predation efficiency. As predation efficiency increases, less time is spent searching for and capturing prey, and more time is available for other behavior, including inactivity. Therefore, if harbor porpoises are efficient predators, it seems reasonable to suggest that only a small portion of their day would be spent engaged in foraging behavior.

Many other mammalian predators are inactive for large portions of the day. For example, Serengeti lions, *Panthera leo*, are inactive for about 85% of each day (Schaller 1972). Similarly, spotted hyaenas, *Crocuta crocuta*, are inactive for 84% of the day (Kruuk 1972). Even the sea otter, *Enhydra lutris*, with a metabolic rate 2.4 times that predicted for a terrestrial mammal of equal size (Costa and Kooyman 1 W"), spends only 34% of each day foraging (Loughlin 1979).

The ventilation sequences recorded from RT-2 and RT-4 suggest that these harbor porpoises restricted the majority of their activity to daylight and evening hours (Table 2). I f a circadian pattern of activity exists, it may be related to the schooling behavior of prey species. The structure of herring schools breaks down after dusk, as the visual cues used to maintain school structure become inoperative (Brawn 1960). Thus, the fish exhibit a dispersed distribution at night, presumably limiting prey capture by predators such as the harbor porpoises, which rely on dense schools to maintain maximum capture efficiency

Other odontocete species exhibit various circadian patterns of activity. Observations of captive bottlenose dolphins indicate that, like the harbor porpoise, *Tursiops* is relatively inactive at night (McBride and Hebb 1948; McCormick 1969; Saayman et al. 1973). In contrast, Hawaiian spinner dolphins, *Stenella longirostris*, rest during the day and feed almost exclusively at night (Norris and Dohl 1980). The prey of spinner dolphins undertake extensive vertical migrations (Perrin et al. 1973) and may be more available to the dolphins at night.

We were interested in observing the nocturnal behavior of harbor porpoises (when they were presumably relatively inactive) under conditions of strong winds and heavy seas, when surface resting was not possible. Ventilat ion data recorded from RT7 during a 5-h period (0000.0500, 5 September 1982) of heavy seas consiste d almost exclusively of Pattern B sequences. Watson and Gaskin (1983) have suggested that this ventilation pattern is expressed primarily hy foraging porpoises, but it seems unlikely thut KT7 (a calf) was foraging for 5 consecutive hours at night. An alternative explanation is that the porpoise was resting underwater and rising to the surface for a series of breaths (free similar observations by McBride and I lebb 1948; Layne 1958; McCormick 1969; Comfy et al. 1978). It is possible, therefore; that harbor porpoises engaged in diverse behavioral activities mny exhibit similar ventilation patterns.

During the period of reduced activity (from 0000 to 0600) radio-tagged porpoises were often located in open water some distance from shore. This may reflect a tendency for porpoises to rest in areas where the hazards of swift currents and shallow waters are minimized. Observations made in the inshore waters of the Deer Island region confirm that porpoises seldom rest at the surface in nearshore environments (Watson and Gaskin 1983).

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AN ARGOS-MONITORED RADIO TAG FOR TRACKING MANATEES

SPECIAL ANIMAL TRACKING

background

Field applications of satellite-monitored radio tags to marine mammals have had short-term success during experiments with humpback whales (Mate et al, 1983) and gray whales (Mate et al, 1984) This paper describes a totally new tag design for an Argos PTT and ita Performance during its first field trial on a weat indian manatee (*Trichechus manatus*) along the west coast of Florida.
The manatee is an endangered mammal and a fully aquatic herbivore. These animals typically swim slowly in shallow waters and feed almost continuously on freshwater and marine plants. In the summer, manatees are found as far north as North Carolina, but during winter their range extends north ordy as far as Florida. These *seasonal changes* in distribution reflect the manatee's intolerance of cold water. Most of the derailed information available on the movements of individual manatees has been collected with short-range VHF radio tags during the winter, when some manatees go up a few rivers having warm springs. There is little information available on the movements of manatees from March to November, because the animals move into saltwater, where the short range of VHF radios precludes tracking. Such information is important for an understanding of manatee home range, foraging strategies, and energetic.

methods

On 5 February 1985, a captive adult mrde manatee, named "Beau", was fitted with a Telonics Platform Terminal Transmitter (PTT) in a specially designed housing. Beau had been in captivity since January 1979, when he was found in Gulfport, Mississippi suffering from cold stress. He was originally rehabilitated at Sea World of Florida and then moved to Homosassa Springs Attractions. Prior to its tagging, the manatee was moved to the Homosassa Spring itself, which is the source of a tributary running into the Homosassa River. The tagged manatee was limited to a 500 m diameter area for two weeks by a wire fence crossing the tributary. During this impoundment, we evaluated the accuracy of PTT locations, the performance of the attachment and the manatee's behavior. The manatee was released into the Homosassa River 14 days after tagging (19 February). The release was made two weeks before offshore water temperatures were expected to be warm enough for manatees to tolerate so the released manatee might "learn" that rivers were warm water refuges. Fifty days after ita attachment, the PTT-equipped manatee was located with a Telonics TR-2 Argos uplink receiver and the PTT was removed.
The U.S. Fish and Wildlife Service developed an attachment system for VHF tags (Rathburn, in prep.), which was also used for the PTT. A strap around the caudal peduncle of the manatee secured a 2 m flexible nylon rod by a swivel. At its other end, the nylon rod was attached to the floating PTT through another swivel. The Telonics-built PTT was housed in a PVC tube 35 cm long and 4.5 cm in diameter. Both PVC end caps were made water-tight by O-ring seals. One end cap was a 4.5 cm long cone designed to shed weeds which attached to the nylon rod through a swivel at its tip. The other end cap was flat with a stainless steel insert to act as a ground plane and base for a 12 cm external whip antenna. The positively buoyant PTT floated vertically with the antenna and 3-4 cm of the housing above water when the manatee was not swimming.
The PTT transmitted once every minute and sent activity and PTT temperature data encoded as 32 bits following the PTT identifier. The activity data related to mercury switch closures when the PTT tipped more than 90 degrees. Transmissions included summaries of the number of times the mercury switch closed in the preceding 30 minute period and during the previous 6 hour period. Internal temperatures of the PTT were measured to the nearest 0.03 degree C. Service Argos calculated locations when enough messages were available. Locations were calculated on the basis of 3 different Service Argos criteria. Location and sensor data were recovered from Service Argos in three ways. 1) U.S. Fish and Wildlife personnel collected telex files at least once each day using a Radio Shack Model 100 portable computer to interrogate the Argos computer files through Tymnet and Transpac;
2) OSU personnel collected dispose files every t2 hours on an IBM PC/XT through Tymnet and Transpac; and 3) Service Argos supplied print outs of all received data. This paper analyses the differences between these 3 data sets and their relevance to biologists collecting field data.

results

Control observations (before release):

During the 14 days before the manatee's release, 105 orbits achieved elevations greater than 5 degrees above the PTT's horizon. Daily checking of the telex files revealed 17 Argos-determined locations from the impoundment area, while twice daily checking of the dispose files revealed 31 locations. A print out from Service Argos revealed that 443 messages were received on 80 of the orbits (76%) achieving more than 5 degrees of elevation. Sufficient data *were* received on 46 orbits (44% of those > 5 degrees) to calculate a location. Table 1 shows the distribution of messages between orbits acquiring new data and what Service Argos criteria were used in determining locations.

❑ Table 1: The classification of 80 orbits which squired new data (during 105 orbits > 5 degrees) from a PTT-tagged manatee in Florida from 5 February to 19 February 1985.

The ability to calculate locations from more than one orbit accounted for 6.5% of the calculated locations. There was art average of 3.3 Argos-determined locations/day prior to release of the tagged manatee. During most of this time there was a transition occurring between the use of NOAA 6 and the testing of the new NOAA9, so that only NOAA 7 was operating dependably.
The mean latitudea and longitudes of the 46 locations were not significantly different from the true geographical center of the spring. The mean distance from the Argos determined locations to the center of the spring was 313 m. This is an excellent fit with the actual dimensions of the spring arcs (250 m radius), particularly as the manatee could have been almost anywhere within the spring. An analysis of the distance-s from the spring center to all Argos-determirred locations revealed that 45'?0 were within 200m, 65Q0 were within 300 m and 80'70 were within 400 m. Only 6% of the locations (n =2) were outside of 600 m and these were both less than 2 km from the spring center.

The temperature of the spring is quite consistent. The mean PTT temperature for 292 transmitted messages prior to release was 23.70 degrees C. Temperatures from 21 to 25 degrees are most likely and 95.2% of all message-s were within this range.

Fourteen messages (4.8%) reported temperatures outside this range. An analysis to determine if bit synchrony errors were responsible for some or all of these messages was not performed. Service Argos predicts that bit synchrony errors will be responsible for errors in as much as 15% of the reported data when all 256 bits of sensor data are sent and may account for some of the observed errors.

Post-release:

From 05 February to 15 March, 52 locations were acquired from dispose fries. The manatee stayed in the Homosassa *River* for 4 days and then moved northwest about 75 km along the nearshore ocean over a two day period to the Suwannee River, where many manatees commonly spend the summer. After 22 days in the Suwannee system, the tagged manatee moved approximately 50 km south to the Withacoochee River, where he stayed until the tag was removed 7 days later. When the manatee travelled from one area to another the activity sensors reported high counts, confirming swimming activity, When the animal was more sedentary, the activity sensors reported low counts, which probably reflected grazing activity.

The mean temperature from 738 messages following release was 21.81 degrees Celsius. Temperatures as low as 17 degrees were recorded during the animal's open ocean movements between the warmer waters of the Homosassa and Suwannee River systems. Daytime temperatures (0600-1800) were significantly *lower* (mean = 21.26 degrees C, n = 406) than night (1800-0600) temperatures (mean = 22.49 degrees C, n = 332).

The reason for this difference is *not yet* known, but likely reflects a change in manatee activity patterns. Because night observations are very difficult, sateltite-monitored radio tags are an important tool to discover differences in diurnal movements and activity patterns.

discussion

The number of locations/day increased dramatically once NOAA-9 was brought into regular service, *resulting* in up co 8 locations/day. Fewer locations were received when the animal was actively swimming, *as indicated* by large distances between successive locations and the activity sensors.

Among all the marine mammals, manatees are probably the most suitable for satellite tracking. Although they inhabit sub-tropical areas where satellite passes are less frequent than at higher latitudes, manatees are shallow water inhabitants and generally slow moving. Thus, with a floating transmitter, regular transmissions can be expected. This experiment demonstrates that it is possible to satellite-monitor animals in marine environments for relatively long periods of time. Activity sensors and temperature data have proven useful in confirming the manatee's movements and habitat preferences.

Both dispose and telex files worked well for a once daily assessment of manatee movements. Our ground truthing before release was accurate enough to detect small scale movements for habitat utilization studies.

The calculation of a location for 76% of all orbits obtaining data is the best record achieved by any marine mammal. However, 10 orbits, which acquired 5 to 10 messages, failed to achieve a location and represented 21.7% of all orbits with 5 or more messages. This may be a distressing factor for other studies of marine mammals, such as whales, which can not be expected to have nearly so many messages/orbit as manatees and for which ground truthing will be quite difficult. We recommend that Service Argos attempt to provide a spectrum of user services with more flexible software options when they next have an opportunity to redesign their systems. Examples of useful user options would include:

1) location determinations from as few as three messages, even with reduced accuracy;

2) direct access to full data sets in archives and

3) retention of dispose/telex files for longer periods.

This paper is only a preliminary report of an experiment which is still in progress. Fifty days after the initial tagging, the manatee was relocated and the PTT removed. New batteries were installed and the PTT was reattached to the same animal. As of 20 May the PTT was still attached and performing well. As ocean temperatures warm, the PTT-equipped manatee may start ranging farther from the river systems to use the nearshore waters of the Gulf of Mexico. This will be exciting, as virtually nothing is known of manatee ocean movements.

acknowledgements

We are indebted to Vin Lally, National Center for Atmospheric Research (Boulder, Colo.) for his help in initiating marine mammal tracking with PTT's, his sustained interest and continued support; to Dave Beaty, Stan Tomkiewicz, and Boyd Hansen, Telonics, for their generous contributions of time and equipment; and to the Homosassa Attractions for their cooperation.

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Code	Disposition	N	% du total / % of total	Moyenne des messages / av. # of messages
0	Pas de localisation	34	42,5	3,79
0	No location	34	42.5	3.79
1	Localisation à partir de 2 passages consécutifs	3	3,8	7,67
1	Location from 2 consec. orbits	3	3.8	7,67
2	Localisation a partir de 2 Passages de 2 satel.	0		
2	Location from 2 orbits of 2 sat's	0		
3	Localisation sur un passage unique	43	53,8	6,67
3	Location during single orbit	43	53.8	6.67
Total		80		5,54
		80		5.54

(4)

Part of unpubl. Ms to be submitted to FLORIDA MARINE RESEARCH PUBLICATIONS

18 Nov 86 draft

MANATEE (*Trichechus manatus*) DISTRIBUTION AND MOVEMENT PATTERNS IN NORTHWESTERN PENINSULAR FLORIDA

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Radio Telemetry

Manatees have been radio-tracked along the southern Big Bend coast every winter from 1978/79 through 1984/85. The radio transmitters were attached directly to a belt around the peduncle from 1978/79 through 1980/81 (for details see Bengtson, 1981; Powell and Rathbun, 1984). This attachment, however, was of limited use because the transmitter antennae rarely emerged from the water, which often resulted in severe attenuation of the radio signals due to the high electrolyte content of river and sea water. Beginning in 1981/82 a new attachment was used. This consisted of a peduncle belt similar to the one used previously, an adjustable quick-fastening belt buckle, and a floating transmitter tethered to a swivel on top of the buckle (Fig. 2). We tagged approachable free-ranging manatees by slipping the belt over their tails and onto the peduncle. The stainless steel buckle permitted us to tighten the belt quickly and then lock it in place when a good fit was achieved. The 4 mW VHF (very high frequency) transmitters produced 35 msec. long pulsed signals. Each transmitter had a unique frequency between 164 and 165 MHz, and individual pulse rates varied between 35 and 80 per minute. The predicted life of the batteries was about 24 months. The

transmitter, battery, and magnetic on-off switch were housed in a polypropylene tube 3.8 cm in diameter and 23 cm long. One end was capped with a 7 cm long nose cone and the other with a plate that included a 1/4 wavelength whip antenna. The cylinder floated upright with about three centimeters above water. This enabled the transmitter antenna to extend out of the water, which prevented signal attenuation. The housing was attached to the peduncle belt with a two-meter long nylon rod 0.95 cm in diameter. The proximate end of the rod was fitted into a 7.6 cm long stainless steel pipe with a hole through its flattened end. The nylon was held in this "joiner" with a stainless steel dowel pin. A groove machined around the nylon rod inside the joiner served as a weak-link with a breaking strength of about 150 kg. A small stainless steel screw-gate chain connector was used to attach the joiner to the swivel on the top of the buckle. The distal end of the tether was formed into a 3 cm diameter tear-drop shaped loop. A stainless steel eyebolt was slipped onto the loop and then screwed into the end of the nose cone of the transmitter housing (for more details of the design and construction of this tag see Rathbun et al., 1986). We observed oo i l affects of this assembly to the manatees.

Peduncle-belt transmitters were applied to four different m oatees at Crystal River in winters 1978/79 and 1979/80, five in 1?80/81 and one in 1981/82. Beginning with the winter of 1981/82, after about 18 months of development using captive manatees, three Crystal River animals were tagged with prototype tethered, floating transmitters. These first tether assemblies functioned for seven, 98, and 105 days. In 1982/83 22 modified floating transmitters, as described above, were deployed at Crystal River and the next winter we attached five more to animals at Homosassa River. The longevity of the 27 tethered assemblies varied between six and 253 days. Each year the manatees were tracked during the summer aerial surveys and opportunistically from shore and boats. During the winter of 1979/80 three of the Crystal River animals were tracked from boats for 24-hours a day for one week each. Locations were determined every five minutes, when possible. The manatees tagged in the Homosassa River were tracked intermittently on 37 days, mostly during day-light hours, from January through June 1985.

In 1979 a 275 cm long cold-stressed male manatee (named Beauregard) was rescued near Gulfport, Mississippi, and rehabilitated at several oceanaria in Florida. Beauregard was tagged with a floating satellite platform transmitter terminal (PTT) attached to a tether assembly on 6 February 1985, while in captivity at the Homosassa Springs Nature World Attraction at the headwaters of the Homosassa River. He was released into the wild on 19 February 1985 and tracked using the Service ARGOS locating system on NOAA Tiros-N satellites (for details of satellite tracking methods see Mate, et al., in press). The satellite location system was ground-truthed between 6 and 14 February 1985, while Beauregard was captive. The mean error between the actual and satellite-determined locations was 202 m (SD=146, range 78-599 m, N=17). The PTT was removed for battery replacement, and exchanged with a VHF transmitter, 44 days after it was attached on 6 February 1985. The PTT was reattached on 15 April and functioned for 62 days, until its battery failed on 15 June 1985. The data on Beauregard included in this paper are preliminary. A comprehensive analysis is in preparation.

RESULTS

Spatial Distribution

Beauregard was successfully located by satellite at least 227 times at the Suwannee River during 83 days (mean=2.7 locations/day) between 24 February and 15 June 1985 (for more detailed analyses see Mate et al., 1986). Beauregard used four principal areas at the mouth of the river (Fig. 6). In decreasing order these were the mouth of East Pass (Segment G in Fig. 6), Barnett Creek (Segment H), the mouth of West Pass and the reefs just north of West Gap (Segment E), and the mouth of Salt Creek (Segment C). These are all principally estuarine areas between the river itself and the offshore oyster bars (Fig. 6). He also used the headwaters of several small creeks, but relatively few locations were in the river channels and dredged canals.

Movements

Twenty-four manatees fitted with VHF radio transmitters (13 males, 11 females) dispersed from Crystal River with functioning units during the six winters of tagging. The furthest or last locations obtained from these animals (in decreasing order) before their signals were lost or they returned to Crystal River were Suwannee River (11 manatees), Withlacoochee River (4), Salt River (3), Crystal River and FPC effluent (2 each), and Homosassa and Chassahowitzka Rivers (1 each). Two manatees (CR05M and CR21M) each made an additional round-trip from the Suwannee River back: south to the Homosassa River in one case and the Withlacoochee River in the other, respectively. A third (CR172M) made two round-trip journeys south during the same summer. He was tracked to the mouth of the Suwannee on 25 March 1984 after being tagged on the 12th at Crystal River. On 4 April he returned to Crystal River and then on 24 April he was back at the Suwannee. On 29 April he was tracked at the Withlacoochee River and on 6 July he was seen at the mouth of the Suwannee River again. He was last tracked in September at the Suwannee. In early December, he returned to Crystal River for the winter, without his radio assembly.

The tracking data from the instrumented manatees can be used to assess the relative use of the major river systems. Only animals tagged at Crystal River and loci determined electronically (no visual sightings) were used. Most of the locations were determined during the coastal aerial surveys, although some also were made from shore or boats. No attempt was made to correct for effort nor the different longevities of the transmitters or attachments. These data (Fig. 22) indicate that there was more traffic from Crystal Rivet to the north along the coast (41.2% of movements) than to the south (17.6%) and relatively little movement occur-red directly between sites located north and south of Crystal River (11.8%). There was much more traffic between sites located north of Crystal River (25.5%) than between sites south of the river (3.9%). The waterways that were the focus of most traffic (in decreasing order) were the

Crystal, Withlacoochee, Suwannee, and Homosassa Rivers and the FPC power plant effluent canal (Fig. 22).

Because of the difficulty of following manatees instrumented with VHF transmitters over long periods of time, we have been unable to determine the travel routes manatees use between river systems and how fast they travel. Satellite telemetry has helped reduce this data gap. After Beauregard was tagged at the headwaters of the Homosassa River, he moved slowly to the mouth of the river in two days. On the fourth day he swam north, reaching Cedar Keys within 23.1 hours. It took him a maximum of another 25.3 hours to reach the mouth of the Suwannee River from Cedar Keys (Figs. 1 and 3). From 24 February through 18 March 1985 he remained in the area of the Suwannee River. He took less than 16.5 hours to move from the mouth of the Suwannee River to Cedar Key and another 27.5 hours to reach the mouth of the Withlacoochee River on 19 March 1985. The Cedar Keys locations indicate he probably swam near shore (Fig. 3). Beauregard's FTT was removed at the Withlacoochee River (Fig. 7) on 26 March 1985 for battery replacement, and was exchanged with a VHF transmitter. On 15 April 1985 Beauregard was found back at the Suwannee River, when the VHF unit was removed and the PTT was reattached. He remained at the Suwannee until 15 June, when the batteries in his second PTT failed. Four visual sightings were made in the area of the Suwannee River mouth between 21 June and 23 July 1985, when the intact PTT was removed. The fate of Beauregard is unknown since this last sighting.

The data gathered in 1981 from the three Crystal River manatees that were tracked intensively are especially interesting because it is the first detailed infer-mation on movement patterns within the river. The three showed different patterns based on a common theme (Fig. 23). They all were dependent on the artesian springs in Kings Bay for warm water, and made foraging trips away from these sites. Most of these trips fit a pattern of leaving war-m-water sites in mid-morning, slowly moving into central or northern Kings Bay by afternoon, and then swimming downriver at dusk. The animals often waited at the confluence of the Salt River for high tide, when they swam either out Salt River to feed on the *Ruppia maritima* beds associated with Salt River and Crystal Bay, or down Crystal River to the *R. maritima* beds along the banks of the river mid-way to the mouth. During these forays into salt water the tagged manatees often were lost due to signal attenuation (belt-mounted transmitters were used). By dawn the next morning they would be back in Kings Bay “es,. a spring. This pattern was best illustrated by Bert (CR23M) (Fig. 23A). The three manatees differed, however, in the amount of time they spent near springs, the number of trips they made away from these sites, and the distance they travelled. The relative importance of different sections of the river was obtained by tabulating the locations of these three animals per river segment (Table 2). Nearly 75% of the loci fell within Kings Bay, while each of the segments downriver had between 0 and nearly 7.0% of the locations. Because Kings Bay was an important aggregation site, the loci for each animal were plotted on large-scale .(L.I-l<il survey maps of the bay. The distribution patterns for the three

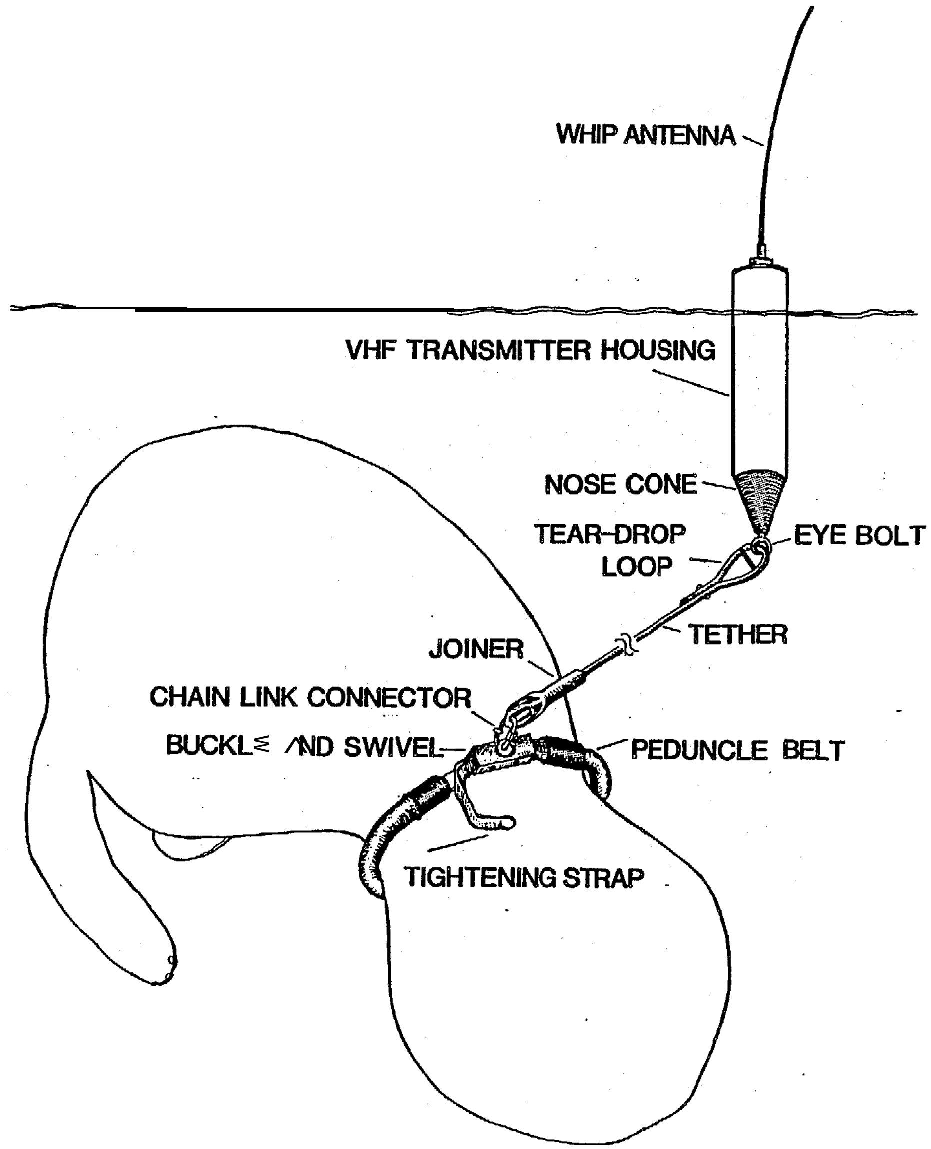
manatees were very ?. 1(111 ar (Fig. 24), but showed some interesting variation that was closely related to their different patterns of movement (Fig. 23). Bert used the Main Spring area as a warm-water refuge, but made frequent trips into mid-bay and two long trips downriver. Gus (CR108M) used two warm-water sites (Main Spring and Magnolia Spring) for long periods of time. When he left these refuges (three times) he made long trips down river. Pickle (CR41F) was the most erratic of the three, spending little time in any major spring, but occasionally visiting the edges of Tarpon Arid Magnolia Springs. She spent much of her time in northern Kings Bay and downriver. Unfortunately, it is not possible to relate the different movement patterns to changes in the environment, because there is no way to unravel the effects of temperature, time and individual variation in this small sample. A composite of all three animals (Fig. 24D) clearly illustrates that nearly the entire bay was used by these manatees at some time. The composite also shows those areas of the bay that were especially important, such as the springs.

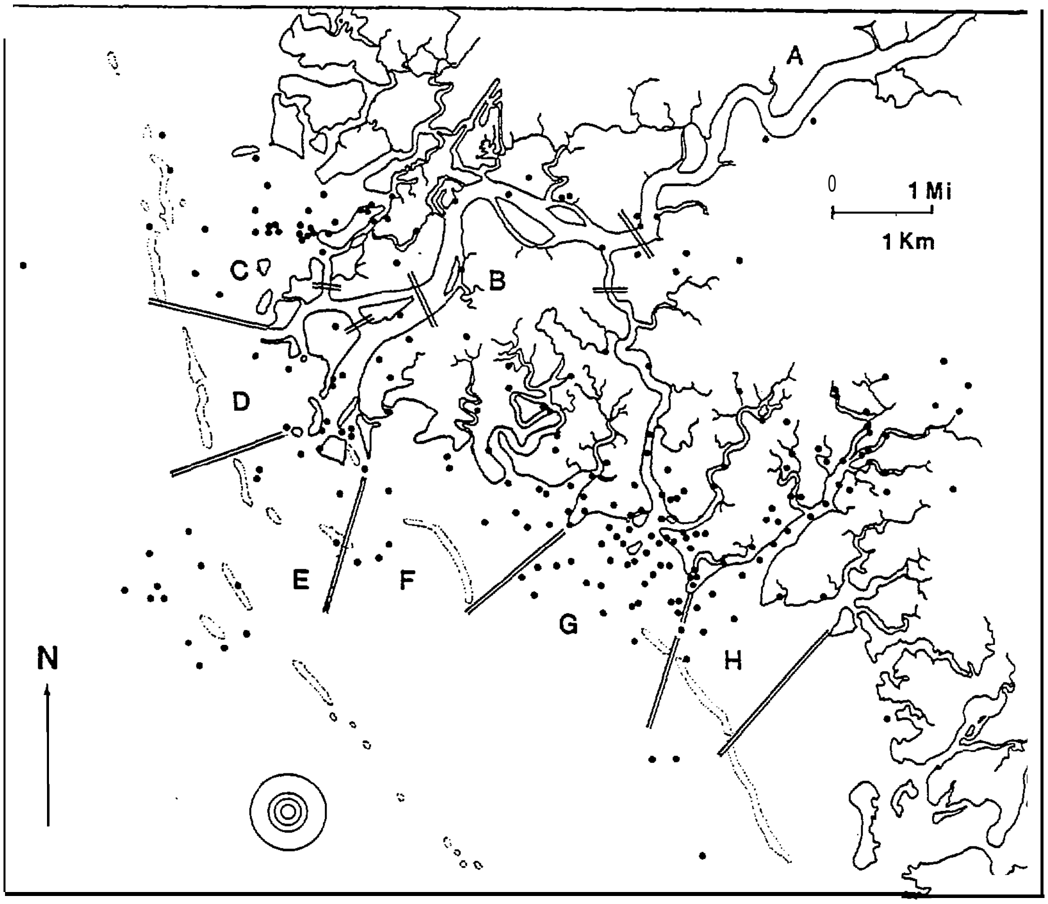
Because we radio-tracked the five Homosassa animals opportunistically, we were not able to determine actual movement patterns of Individuals, as was done for Crystal River. A diel pattern was observed, however, that was similar to the manatees tracked at Crystal River. In mid-morning (ca. 9:00 a.m.) they started to leave the immediate areas of warm water and spent much of the day dispersed in Blue Water bottom-resting, milling around, and interacting socially with each other. In late afternoon they would start to swim down river and by dusk, or soon after, they would reach the confluences of Salt River and Price Creek, where they would feed on the dense beds of *R. maritima* and *Potamogeton pectinatus* that grow on the mud flats. The next morning, they would be back in Blue Water. The manatees only went up to the Fish Bowl Spring when it was exceptionally cold and when there was a high tide that allowed them to swim up the shallow channel. Most often the animals aggregated near the boat dock downstream of the main (fish bowl) spring at Homosassa Springs Nature World Attraction (Fig. 15).

The floating transmitter housings and antennae were colored distinctively, which permitted visual identification of the tagged manatees (often by the public) without the aid of the radio signal. These sightings, along with those based on distinctive scar patterns, provided additional information On movements. The furthest north that known individuals travelled from the Crystal and Homosassa Rivers was the Wakulla River on the panhandle of Florida (Fig. 1 and Table 5). To the south, the furthest record is Sanibel Island near Ft. Myers (Powell and Rathbun, 1984). There are two records from Tampa Bay. The transmitter on CR188M failed soon after he was tagged, but he was seen in the Tampa Bay area by members of the public on four occasions during the summer of 1984. Locations included Boca Ciega Bay, the Hillsborough River, and the Alafia River. The second case was TB22M, who was not radio-taqgert, but was identified several times by the very distinct and large white scar on his back. He was first sighted at the TECO Big Bend power plant effluent in Tampa Bay in February 1983. In August

1983 he was seen at the mouth of the Suwannee River. The next sighting was in Blue Water in April 1984. A year later, in July, he was at the mouth of the Suwannee River again. This manatee seemed to winter in Tampa Bay and move north to the Suwannee River (via a short visit to Homosassa) during the summer. This pattern was corroborated by the lack of winter sightings at Homosassa or Crystal Rivers.

Figure 2.
Assembly used to attach f oating radio transmitters to manatees.





gure 6.
Distribution of satellite-determined locations (N=227) of Beauregard at the mouth of the Suwannee River during 83 days from 24 February 1985 through 15 June 1985 (dots). Bold parallel lines define segments A-H. Four concentric circles represent the 30%, 65%, 80%, and 100% probability, respectively, of a satellite fix being within each respective circle. Percentages were derived from 17 fixes while Beauregard was captive at the headwaters of Homosassa

Figure 22.
Patterns of manatee movements based on 24 individuals radio-tagged at Crystal River from 1979 through 1985. Only locations determined with radio-signals were used. No correction for effort was made. Numbers within circle=total movements BETWEEN waterways and numbers in parentheses=total movements to or from EACH waterway. The waterways are ordered geographically from north to south in counterclockwise direction from the Suwannee River.

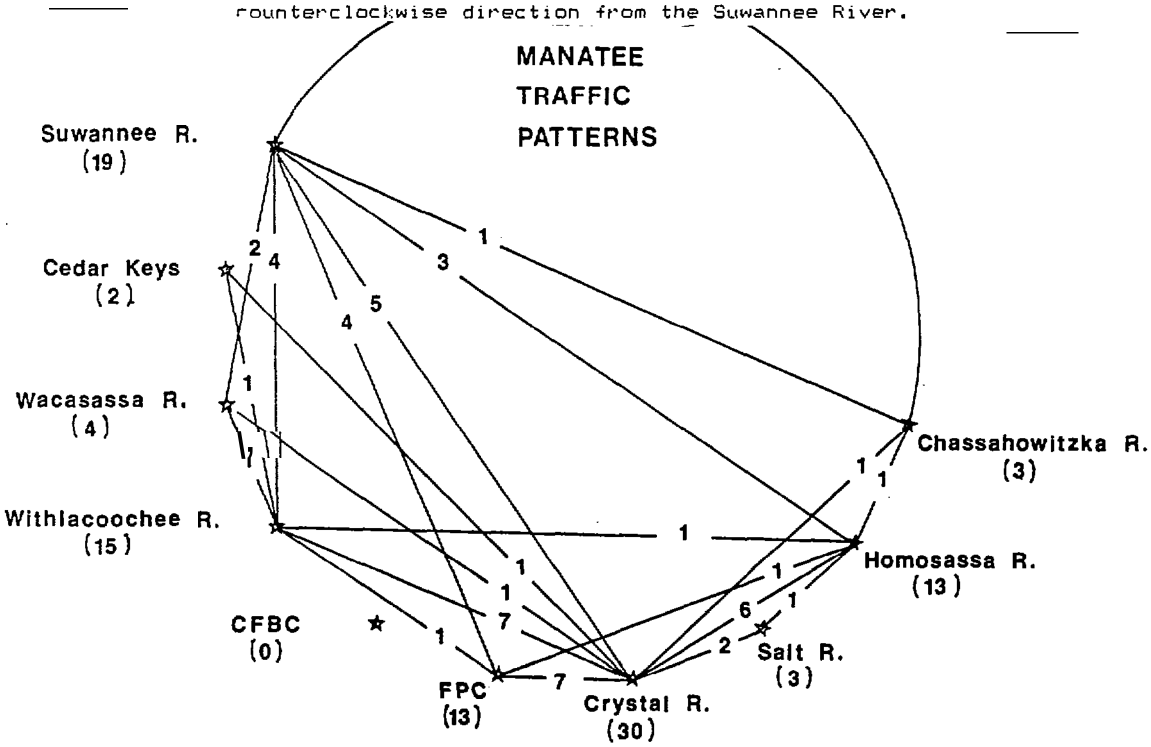


Figure 23.
Temporal and spatial patterns of movement for three manatees radio-tracked 24-hours per day for seven consecutive days each at Crystal River. Virtical dashed lines = midnight. Dots are located at three-hour intervals, unless the manatee was not located, as indicated by a broken line. Distance is linear from the most southern navigable canal in Kings Bay to the mouth of Crystal River. Main Spring=0.75 km, Magnolia Spring=1.0 km, Salt River confluence=5.5 km, Salt River mouth=7.0 km, Crystal River mouth=14 km. A=Bert, 26 January-2 February 1981; B=Gus, 10-17 February 1981; C=Pickle, 25 February-4 March 1981.

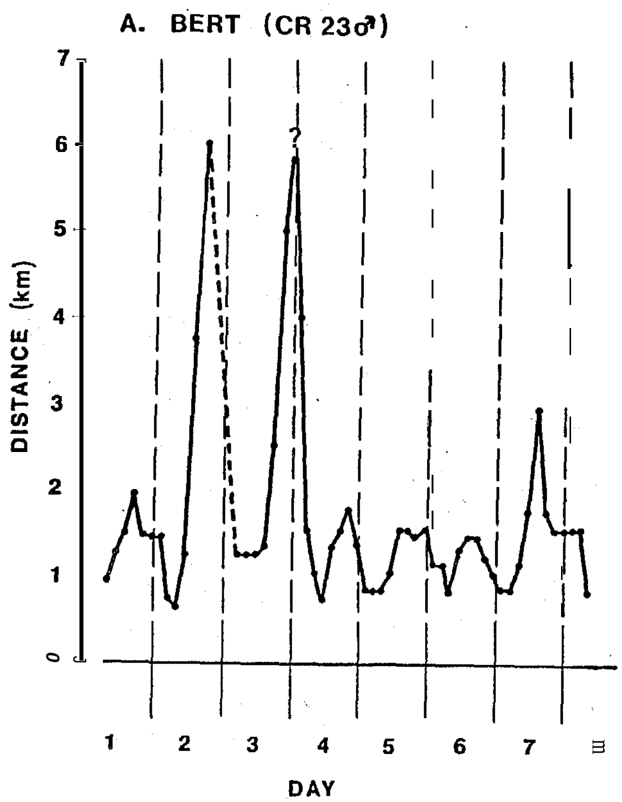
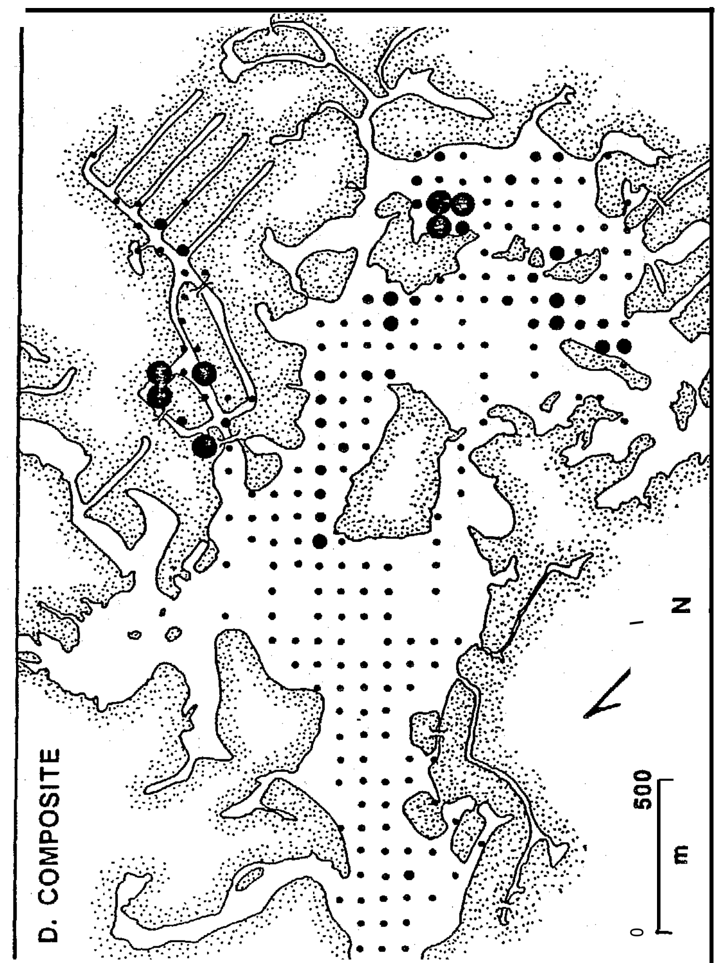


Figure 24.
The use of Kings Bay, Crystal River, by three radio-tagged manatees. Each individual was located every five minutes, 24-hours a day for seven consecutive days. Dot size represents average number of minutes per day spent at each location during the seven days (small=<5.0, medium=5.0-15.0, large=15.1-25.0, giant>25.0). A=Bert, 26 January-2 February 1981, B= Gus, 10-17 February 1981, C=Pickle, 25 February-4 March 1981, D=Composite of all three manatees.



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NEWSLETTER

NOAA … AVRIL / APRIL

SUM D'ANIMAUX
ANIMAL TRACKING

Émetteur pour Dauphins

Le Semite National américain de la Pêche Maritime est en train de développer un émetteur pour l'étude des dauphins en relation avec la pêche du then •ijaune• clans la zone tropicale Est du acifique (fig. 1).

La sauvegarde des dauphins nécessite des information relatives à la répartition, la migration et le mélange qui s'opère entre plusieurs espèces. Les méthodes conventionnelles d'acquisition des données par des navires ou par des avions sent excessivement chères à cause de l'étendue de la zone d'études (environ 13 km²) et de la durée de l'expérience (1 an). Le suivi par satellite serait un moyen très efficace d'obtenir des données régulières.

La conception et la verification de l'émetteur sur des dauphins en captivité et en liberté se poursuivent depuis 1977. Avant que l'emploi du système Argos ne soit autorisé pour le SUM des animaux (1980), tous les efforts de développement avaient été portés sur NIMBUS 6. A present on envisage la conversion au système Argos pour poursuivre les expériences concluantes de NIMBUS 6.

L'émetteur qui pèse 907 g est contenu clans 2 tubes en aluminium dent les dimensions sent lee suivantes : 17,5 x 5 cm (fig. 2). Les composants principaux sont : une batterie 183 V cc (piles au lithium), un circuit horloge principal, un oscillateur RF et un amplificateur de puissance, un interrupter déclenché par l'eau de mer et une antenne fouet quart d'onde.

Le système émet sur 4012 MHz à une cadence de repetition contrôlée par l'interrupteur d'eau de mer qui permet

Fig. I

d'économiser la dun% de la pile par le contrôle de l'émission lorsque le dauphin fait surface. Vers midi, le circuit horloge principal déclenche l'émetteur pendant 4 heures. L'émetteur qui est attaché à la nageoire dorsale du dauphin peut fonctionner tous les jours ou une fois par semaine. Au cows des contrôles opérés sur les dauphins en captivité, l'ensemble est fixé par une sangle (fig. 3). Il est nécessaire d'ajouter des flotteurs lorsqu'on travaille sur des dauphins en liberté (fig. 1) parce que les émetteurs pourront être récupérés. [ls seront éliminés en fin d'expérience en vue de réduire le poids et l'encombrement de l'ensemble. Les dauphins, n'ont pas, apparement, beaucoup de difficultés à s'habituer à l'émetteur.

Nous avons rencontré plusieurs problèmes d'ordre électronique mais en ce moment, le principal semble être le temps de visibilité de l'antenne. Des expériences récentes conduites un dauphin tacheté (Stenella attenuata) en liberté, ont indiqué que les périodes pendant le uelles il restait en surface étaient de %00 à 1500 msec (fig. 4). L'effet des vagues sur l'émetteur réduit encore le temps pendant lequel l'antenne émerge au-dessus de l'eau. La longueur du message pour NIMBUS 6 est de 980 msec.

La duke limite pendant laquelle les dauphins restent en surface ne devrait poser aucun problème au système Argos qui ne nécessite qu'une longueur de message de 300 msec. Il resterait done suffisamment de temps pour émettre d'autres données d'ordre biologique et d'environnement obtenues par des capteurs installés sur le boitier.

Le service National de la Pêche Maritime serait heureux d'avoir des réponses des fabricants intéressés par cette experience.

Jacqueline Jennings
Porpoise Tagging and Tracking Project
Southwest *Fisheries Center*
NOAA-USA

Dolphin transmitter

The U.S. National Marine Fisheries Service has been working on development of a satellite-linked transmitter to study dolphins involved in the yellowfin tuna fishery of the eastern tropical Pacific (fig. 1). Conservation of dolphins requires information on distribution migration, and mixing of several dolphin stocks. Conventional methods of acquiring the data by vessels and "planes are excessively costly since the study area is about 13 million km² and an experiment should last at least one year. Satellite tracking would be the most efficient means of regularly obtaining data

Design and testing of the transmitter on captive and wild dolphins has been in progress since 1977. Since permission to use Service Argos for animal tracking was only granted in 1980, all developmental efforts have been directed at the NIMBUS-6 satellite. However, conversion to Service Argos is anticipated following successful experiments through NIMBUS-6.

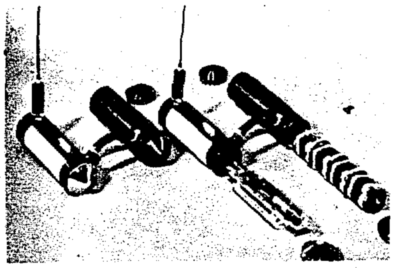


Fig. 2

The present transmitter weighs 907 g and is packaged in two aluminium tubes measuring 17.5 x 5 cm (fig. 2). The major components are : a power supply of 18 3-VDC organic lithium cells, a main timing circuit, an RF oscillator and power amplifier a seawater activation switch, and a one-quarter wavelength stub antenna The system operates at 401.2 MHz with a transmission repetition rate controlled by a seawater switch. The switch conserves battery life by allowing transmission only when the dolphin surfaces. The main timing circuit is usually set for four hours around noon and can operate daily or weekly. The transmitter fits around to the dolphin's dorsal fin During test on captive dolphins the pack is attached with a harness (fig3). Flotation tube are added when working with wild dolphins (fig. 1) so that the transmitters can be recovered but will be eliminated from the final models to reduce the weight and bulk of the pack. Dolphins seem to have little difficulty adjusting to the pack

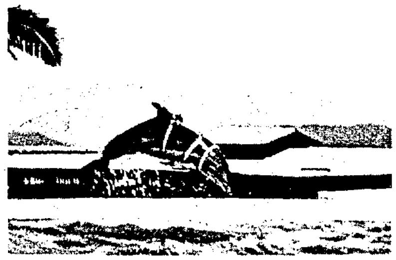
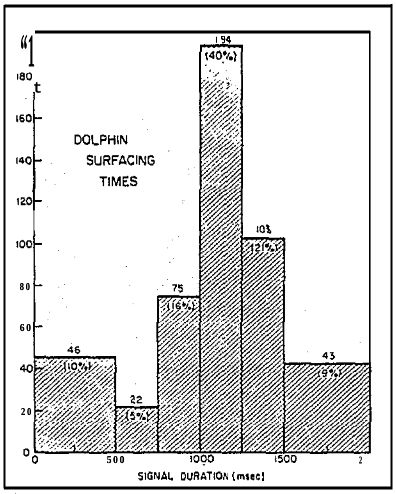


Fig. 3

Notons que l'antenne a été déplacée vers l'avant

Please note that the antenna has been moved forward.

Several electronics problems have been encountered, but the major remaining problem appears to be the limited time available for full exposure of the antenna Recent tests on a wild spotted dolphin (Stenella attenuata) indicated that most surfacing times were from 1000-1500 msec (fig. 4). Splashing significantly reduces the time the antenna is clear of water. The message length for NIMBUS-6 is 980 msec.



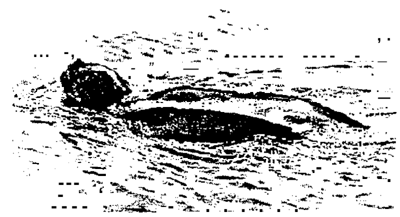
ig. 4

The limited surfacing times of the spotted dolphins would not be a problem with the Service Argos system which requires a basic message length of only 300 msec. Time would still remain for transmitting other biological and environmental data obtained by placing sensors on the dolphin's pack. The Southwest Fisheries Center, National Marine Fisheries Service, welcomes response from any interested manufacturers.

Jacqueline Jennings
Porpoise Tagging and Tracking Project
Southwest Fisheries Center
NOAA-USA

Les Tortues Luth

Considérée par de nombreux zoologists comme le demier reliquat des grands reptiles du secondaire, la Tortue Luth, *Dermochelys coriacea* L. se trouve être l'unique représentant de la famine des Dermochelydés. Elle ne possède pas comme ses congénères de plaques comées ou écaillées, mais une carapace formée dune mosaïque osseuse recouverte par une peau fine, noire, tachetée de dessins géomètriques couleur lavis d'aquarelle. Elle fut nommée improprement *Coriacea* car sa peau, loin d'être « coriace » n'est en fait qu' une simple pellicule tégumentaire qui s'écorche facilement. Sept carènes traversent longitudinalement sa carapace fuselée.



Sa tête massive comporte de puissances mâchoires capables de sectionner une rame. Des dimensions des plus fantaisistes ont pu être données a propos de cet animal, il parait raisonnable d'envisager un poids maximal de 600 kg et une taille ne dépassant pas 2,40m. Comme les Sauropodes du Crétacé, pour une masse importance, elle ne possède qu'un encéphale primitif, minuscule, de 5 g environ. Poussées par une force ancestral, les Tortues Luth viennent pondre de mai à juillet sur les plages sablonneuses de Guyane, où la population est estimée à 15000 femelles, de Floride 200 femelles, de Malaisie 4000 femelles.

Ne connaissant jusqu'à présent que l'adulte de 500 kg et les jeunes nouveau-nés sur ces rivages, on serait tenté de penser que tout leur cycle biologique s'effectue clans ces régions. En réalité cet animal pélagique ne fréquente pas seulement les eaux chaudes des tropiques mais remonte clans les eaux tièdes de la côte européenne et tout particulièrement près des côtes de France, clans un secteur précis bordé par les îles de Ré et d'Oleron : les Pertuis charentais. Ainsi 80 % des observations françaises ont lieu entre 46 ON/l 0,0'W et 46°60'N/1°50'W.

Le premier échouage connu date de 1754. Depuis 1977, des travaux se poursuivent annuellement au Museum d'Histoire Naturelle de La Rochelle pour préciser les caractères biologiques de cette espèce.

Ilapparaît clairement qu'un nombre important de Tortues Luth se trouvent amenées chaque année à fréquenter ce secteur précis des côtes atlantiques françaises au tours de leur cycle biologique.

La Tortue Luth mène une vie solitaire. Ce sent pour la plupart des individus isolés que l'on va rencontrer à partir de la fin juin jusqu'en octobre sur le littoral de la Vendée et de la Charente-Maritime.

Le nombre d'observations annuelles collectées met en évidence une préférence de ces individus pour l'un des Pertuis charentais : le Pertuis breton. En 1978, les 43 individus signalés fréquentaient le Pertuis breton, en 1979, 2 seulement sur 55 et en 1980, 3 sur 28, révèlaient leur présence dons le Pertuis d'Antioche. Le nombre des individus recensés ne peut pas refléter avec exactitude la population présente clans les Pertuis pour plusieurs raisons : l'animal est d'autant plus difficile à observer que la mer est agitée; les information ne sont pas toujours transmises par les pêcheurs pour qui cette apparition pour le moins curieuse devient banale.

Si en Guyane, seules les femelles sent observées, sur le littoral charentais, les deux sexes se côtoient sur des fends de l'ordre de six à dix mètres.

La vitesse moyenne estimée de chaque individu s'élève à 4 nœuds. En quête de nourriture, l'animal prospecte la tête complètement immergée clans les banes de méduses : *Rhizostoma pulmo* constituant l'essentiel sinon la totalité de son régime alimentaire. Le déplacement de ces méduses dû aux courants de marée conditionne les allées et venues des Tortues.

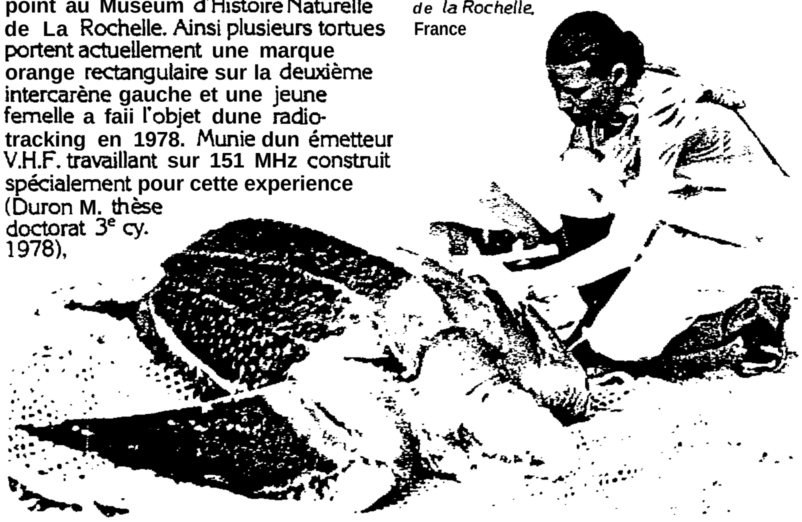
Le comportment et la biologic saisonnière des Tortues Luth clans les eaux charentaises ont pu être connus grâce aux observations en mer régulières et au marquage mis au point au Museum d'Histoire Naturelle de La Rochelle. Ainsi plusieurs tortues portent actuellement une marque orange rectangulaire sur la deuxième intercarène gauche et une jeune femelle a faii l'objet dune radio-tracking en 1978. Munie dun émetteur V.H.F. travaillant sur 151 MHz construit spécialement pour cette experience (Duron M. thèse doctorat 3[e] cy. 1978), la Tortue a été relachée au Sud des Sables d'Olonne a proximité de l'endroit où elle avait été capturée par un chalutier sablais.

Les mauvaises conditions météorologiques (vent d'Ouest fort forte houle Nerd-OuesL mer forte) n'ont pas permis le déroulement souhaité de l'expérience. Ainsi l'animal n'a été suivi que huit jours, et seuls les différents types de plongées : longues (7 à 10), moyennes (2 a 3), et courtes (1') correspondent à plusieurs attitudes (fuite, quête de nourriture, route) déjà observées à la mer, on pu être reconnus.

La forte concentration de méduses : *Rhizostoma pulmo*, la faible salinité des eaux dues aux apports du Lay, la Sèvre niortaise, la Charente, la région où l'insolation est la plus tongue de la côte, expliqueraient en partie les raisons qui [es poussent a se fixer clans ce secteur précis des Pertuis charentais. Mais un grand mystère plane sur leur provenance. La population de Guyane étant la plus importance, il est logique de penser que [es individus observés sur nos côtes proviennent de cette population recensée en Guyane. Empruntant pour ce faire les courants du Mexique, de Floride, puis le Gulf Stream, ces Tortues pourraient ainsi parcourir plus de 5000 km. D'autres hypothèses peuvent être formulées. La population africaine fort réduite, nous fait cependant envisager que certains individus peuvent passer près des Canaries, revenir par les courants jusqu'au Golfe de Gascogne et pénétrer les eaux favorable des Pertuis charentais.

Seul un repérage par satellite pourrait élucider ce mystère.
L'intervention du système Argos va permettre d'établir avec exactitude la route de migration.

Mrne Michèle Duron
Museum d'Histoire Naturelle et d "Ethnographic de la Rochelle,
France

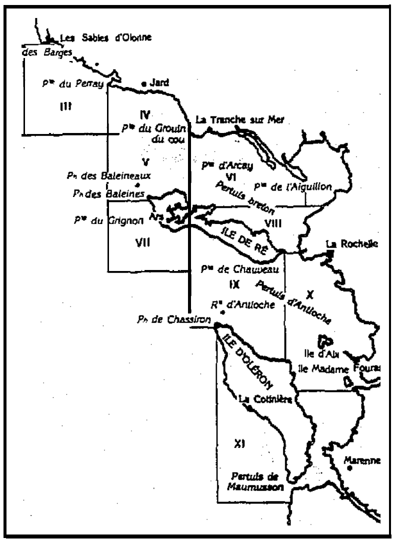


Leathery Turtles

Considered by many zoologists as the fast remaining big *reptile of the secondary era, the Leathery Turtle, Dermochelys Coreacea L., is in fact the* unique representative of the *dermocfelydes family. The turtle does not* haue *a bony or scaly carapace* like other *turtles, it* has in fact *a bony structure carapace* couered with *a thin black aquarelle colour geometrical figure patched skin. It was incorrectly called coriacea,* as *the skin which is* far *from being tough is only a* thin *tegumantry* type *of skin which can be easily tom. Seven longitudinal carenas cross over the turtles carapace It has two enormously powerful* jaws capable of breaking an *oar.* Some incredible dimensions have been *put forward* for this *animal,* yet we *consider it would be more reasonable* to *allow* for a *maximum weight* of 600 *kg* and *a length of 2.4* m Just *like* the *cretaceous Sauropoda, this turtle* only has *a tiny primitive* brain weighing approximately *5 .g.* Urged on by an ancestral *force, the turtles come and lay their eggs between May and July on the sandy beaches in Guyana. The local population has been assessed as* follows: *15,000 females, 200 from Florida, 4,000 from Malaysia.*

As we are only conversant with the 500 kg adults and the newborn turtles we find in *these areas, we were tempted to believe that their entire* reproduction cycle took place *in these areas In fact this pelagic animal does not only bask in warm tropical waters it also comes up the waters of the european costline and especially near French* coastlines. *The area they come to* is between the *Ré and Oléron* islands = *Charentais Pertuis area. Thus, 80$ of French observations are done between 40°N/1° 10 W and 46°N/1°50'W.*

Turtles first started coming ashore there in 1754. Since 1977 work has been done each year at the La Rochelle Natural History Museum



Delimitation des différents secteurs d'étude et répartition estivale de *Dermochelys coriacea*

with a *view to pinpointing the* **biological characteristics of this** *species.*

It is obvious **that** *many leathery turtles come* into *this* **area** *each year* **during their biological cycles.**

Leathery turtles lead solitary existences. *We normally only see one turtle at a time between the end of June and October* **on** *the Vendée* **and** *Charente-Maritime* **area** *coastline.*

The number of annual observations collected shows that the turtles prefer one **particular** *Pertuis* area, *that is the Breton Pertuis area. In 1978, all 43 turtles sighted in the Pertuis area were* **in the** *Breton Pertuis, only 2 out* **of** *55 were there in 1979* **and 3 out of 28** *in 1980 in the Antioche Pertuis.* **The actual number of** *recorded sightings* **cannot** *give a true picture of the turtle population in the Pertuis area for various reasons : the animal is difficult to sight in choppy seas; fishermen do not always report on* **the** *presence of turtles as this is becoming an every* **day** *event.*

Only *females haue been sighted in Guyana but both sexes are present in the Charentais coastals area and can be seen between 6 and 10 meters down.*

Average estimated speeds **of** *turtles is 4 km.* ***When*** **it is** ***looking for food the turtles head is completely underwater among the shoals of jellyfish : Rhizostoma pulmo is the main if not the*** *entire portion of* **the** *turtles diet. The turtles tend to follow the jellyfish which are washed in andout* **with** *tidal movements.*

The **behaviour and the** *seasonal biology of leathery turtles in Charentais waters* were *found out thanks to regular sea observations and markings which were perfected by the La Rochelle Natural History Museum. At the moment* certain turtles haue a rectangular orange marking *on* **the left** *second intercarena young was radiotracked in 1987. The turtle* was *fitted out with* **a** *VHF transmitter operating on 151 MHz, specially. built for this experiment (M. Dwvn: Thesis* **for** *PhD)* **and** *was* **set free** *south* **of** *the Sables d'Olonne near the place it had been captured by* a *Sable fishing boat.*

Bad weather conditions (strung wind, high NW troughs, very rough sea) ***did not enable the experiment to be carried out as was desired. In fact we*** **were** *only able to track the animal for 8 days and recognize the various kinds of diving patterns:*

- *7— 10 mn, long diue (flight);*
- *2-3 mn, average diue (flood hunting);*
- *1mn, shod dive {swimming).*

The *following* **may** *partly* **explain** *why the turtles come* **to this** *area :*

. High concentration of jellyfish (Rhizostoma pulmo);

- *high insolation area;*
- *low water salinity rating (due to the river water from the Lay, the Seure and the Charente).*

But there **is a big** *mystery as to where they come from. As the Guyana population* **is** *by far the biggest, it would appear to be logical to think that the turtles sighted off* **our coasts** *come from the Guyana population.*

The turtle would probably go **by the** *Mexico, Florida and Gulf Stream currents and cover more* **than** *5,000 km, but other hypotheses are possible. The african population is very depleted and we have been lead to envisage the following* **possibility — some turtles pass** *nearby the Canary Islands, come back via the currents to the Bay of Biscay and then up to the Charentais Pertuis area.*

A satellite tracking system is the only way of solving this mystery.

Intervention by Service Argos will accurately establish the migration mute of the leathery turtle.

Mme Michèle Duron
Museum d'Histoire Naturelle et d'Ethnographie de la Rochelle, ***France***

SUM
des requins pèlerins

A la faculté de Zoologie de l'Université dAberdeen, **nous sommes en train de développer des techniques de suivi par satellite du** requin pèlerin (Cetorhinus maximus). **Ayant débuté avec le** système RAMS/NIMBUS **nous** projetons toutefois d'utiliser à l'avenir, le système proposé **par** le Service Argos.

Le requin pèlerin, *2'* **poisson du monde de par** sa taille, **pèse 7 tonnes et mesure 9** mètres à l'état adulte. Il se nourrit de zooplancton qu'il filtre **tout en pursuivant sa route. Ce comportement** signifie que le requin se trouve très près de la surface de l'eau en été et qu'on peut facilement **le suivre par satellite.**

La production **primaire de** l'océan **a souvent** été étudiée grâce **à la** télédétection **par satellite des temperatures de surface de** l'eau **et de la concentration en chlorophyll. Des** données simultanées obtenues sur les **movements des** requins pèlerins **en** quête de nourriture **nous** donneraient **des information** supplémentaires **au** niveau tertiaire de la chaîne de nourriture marine. **Nous** espérons découvrir **comment ce** requin **et** d'autres poissons **arrivent** à trouver **et** à utiliser les zones de production élevée.

Nous avons collaboré **avec des** chercheurs de la *Station* **Marine de** Millport (côte Ouest de l'Ecosse) **et avons** développé **une** méthode **pour fiier des plates-formes sur des requins** pèlerins. **Line** ligne de traction **a été** attachée à **la base de la** nageoire **dorsale du requin par un dispositif manuel (harpon).** Puisqu'il **est impossible** d'immobiliser **un** requin pèlerin, **la technique** employée **est** basée **sur le silence et la** rapidité. **On** s'en approche de par l'arrière clans un « Zodiac » **dent** le moteur hors-bord **a été muni dun** silencieux spécial **(fig. 1).**

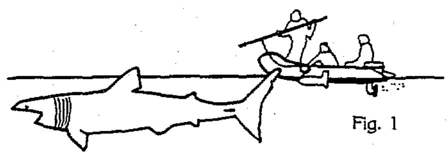


Fig. 1

Technique de fixation de la plate-forme
Une approche discrète depuis l'arrière

PTT attachment** technique **for basking sharks Approach** very **carefully from behind !

L'électronique de base de la plate-forme est contenue clans un boitier pressurisé **qui est logé clans une** bouée **(fig. 2).** L'antenne est placée **clans** l'aileron **de cette** bouée.
Un manocontact **coupe** l'émetteur si

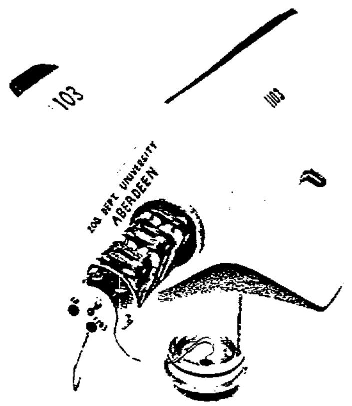


Fig. 2

Electronique de base pour les requins pèlerins fabriquée par l'Université d'Aberdeen.

Aberdeen University Basking Shark PTT.

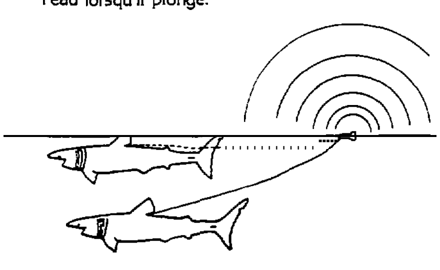
le requin amorce une plongée. Les plates-formes peuvent rester attachées au requin pendant deux mois avant d'être larguées saris lui causer le moindre maf.

On est en train de développer des plates-formes plus petites qui pourront rester attachées plus longtemps.

Jusqu'ici, nous n'avons obtenu qu'une réussite partielle du fait que nous avions rencontré des problèmes de hardware sur les plates-formes. Mais nous sommes convaincus que le suivi par satellite des requins pèlerins contribuera beaucoup à nos connaissances de l'écologie marine pendant les années à venir.

LG. Priede
Department of Zoology, University of Aberdeen Scotland, U.K.

Configuration de traction dune plate. forme démontrant comment la bouée reste à la surface quand le requin se trouve à diverses profondeurs. La flottabilité de la bouée est minime et permet au requin de l'entrainer sous l'eau lorsqu'il plonge.



PTT tow configuration showing how the pod remains on the surface at a variety of swimming depths. The buoyancy of the pod is minimal so the shark can tow it underwater when it dines

Tracking of basking Sharks

In the Zoolog Department of the University of Aberdeen we are developing tecniques of tracking Basking Sharks (Cetorhinus maximus) by satellite, Early work was done with the Nimbus RAMS system but future work is planned using Semite Argos.

The basking shark is the second largest fish in the world growing to an adult weight of 7 tonnes and a length of 9 m It feeds on zooplankton swimming along with its mouth wide open filtering food from the water. This feeding behaviour means it is near the surface of the sea for much of time during summer ("basking") which makes it amenable to radio tracking.

Primary production in the ocean is now often studied by satellite remote sensing of surface temperature and chlorophyll concentration Simultaneous data on feeding movements of basking sharks would provide complementary information at the tertiary level of the marine food chain We hope to discover how these, and presumably other fish, find and utilize areas of high productivity.

We haue together with workers at the Universities Marine Station Millport on the West Coast of Scotland developed a method of attachment of PTTs to basking sharks. A tow line is attached to the base of the dorsal fin of the shark by means of a hand harpoon deuice. It is impassible to immobilise a basking shark so the technique is based on stealth, manœuvring up close to the shark from behind in an inflatable boat with a specially silenced outboard motor (fig. 1).

The electronics of the PTT is enclosed in a pressure proof casing set in a buoyant hull (fig. 2). The antenna is embedded in the upright fin on the pod. A pressure switch inactivates the transmitter when submerged. The PTTs can stay attached for up to two months and are shed without any harm to the shark. Smaller PTTs currently being developed will remain attached for longer periods

We have only had limited success so far mainly due to PTT hardware problems but we are convinced that satellite tracking of basking sharks will make a major contribution in the future to our understanding of marine ecology.

I.G. Priede *Department of Zoology, University of Aberdeen Scotland, U.K*

Suivi d'une tortue marine

Grâce à un projet de coopération entrepris par le Service National américain de la Pêche Maritime et le Service de la vie animale et des poissons, on a pu démontrer la faisabilité de procéder au suivi par satellite de grands animaux marins comme les tortues de mer. Le 16 octobre 79, une tortue marine femelle Dianne d'un poids de 96 kilos équipée dun émetteur-satellite spécialement conçu a été lâchée au large de Gulfport clans le Mississippi en direction du Golfe du Mexique.

L'émetteur fonctionnait avec le système de localisation de plates-formes RAMS embarqué sur un satellite Nimbus. Les données transmises au Goddard Space Flight Center par Nimbus étaient traitées de façon à localiser la tortue avec une précision d'environ 2 kilomètres. L'émetteur avait été conçu pour une période de fonctionnement dun an avec une fréquence d'émission de 8 heures tous les 4 jours.

Construit par Handar Corporation, l'émetteur était logé clans un flotteur plastique cylindrique étanche de 15,24 cm de diamètre et de 25,4 cm de long. A l'intérieur du flotteur se trouvait une balise radiogoniomètrique qui devait perrnettre aux avions légers et aux embarkations de surface de localiser Dianne grâce à leurs récepteurs portatifs. Dun poids total d'environ 3.2 kg, le flotteur était attache par une corde nylon de 76,2 cm de long au dos de la carapace de la tortue de façon a perrnettre à l'émetteur de faire surface chaque fois que Dianne remontait pour prendre de l'air.

Avant d'être lâchée et pendant sa période de captivité, Dianne avait fait l'objet d'études au moyen d'instruments électroniques. Pendant cette période nous avions pu évaluer son comportment avec l'émetteur attaché à sa carapace. Les études ont montré que le flotteur ne gênait pas beaucoup le comportment naturel de la tortue.

A partir du moment où elle a été lachée, Dianne a fait route vers le Sud en contournant l'embouchure du Mississippi, ensuite vers l'Ouest le long des côtes de la Louisiane et du Texas puis vers le large de Galveston (Texas). A partir d'un hélicoptère fourni par les Garde-Côtes américains, une mission avait pour objectif de photographer et d'observer l'animal, devaluer subjectivement son état physique et de s'assurer que

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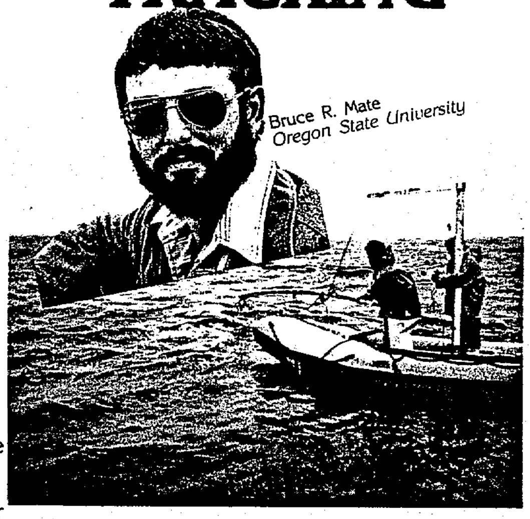
NEWSLETTER

AVRIL-APRIL 1984 N° 19

Spécial biologie · Special issue biology

sum D'ANIMAUX

ANIMAL TRACKING



Bruce R. Mate
Oregon State University

SUIVI DE BALEINES

‘ Technologies

Le NCAR (National Center for Atmospheric Research), Oregon State University et la société Telonics ont mis au point une balise Argos, désignée « Satellite Whale Tag » ou SWT, pour être placée sur des baleines. L'électronique est fabriquée par la société Telonics de Mesa, Arizona (USA), et la première SWT a été placée sur une baleine en juillet 1983.

Le boîtier est en aluminium et de forme cylindrique. Il mesure 14 cm de diamètre et 7,6 cm de long, et pèse 3,52 kg. Line des extrémités du boîtier est solidaire d'une plaque de support en acier inox. L'autre extrémité est coiffée dun couvercle étanche en polyuréthane haute-densité moulé, de couleur orange. Celui-ci est surmonté dune antenne en hélice tronquée et d'un interrupter déclenché par l'eau de mer. La forme du couvercle a été tongue de façon à faciliter l'écoulement de l'eau (quand la baleine fait surface) et à assurer la rigidité mécanique nécessaire de la base de l'antenne qui est, par ailleurs, très souple. Des attaches, ou ancres, dites de type « parapluie » passent à travers des fentes à chaque bout de la plaque de support. La SWT, équipée de sa plaque de support et de ses ancres, est placée sur le dos de la baleine et les ancres déployées par un applicateur spécial utilisant des cartouches à pression à déclenchement électrique. En général, les balises sent fixées sur des baleines prises clans des filets. Ce travail est effectué par une équipe à bord d'un petit bateau se servant d'une longue perche pour poser la balise et l'applicateur sur le dos de la bête.

Deux capteurs sent employés : l'un pour mesurer la température à l'intérieur du boîtier, l'autre pour mesurer la durée de chaque plongée (c'est-à-dire, le temps entre l'immersion de l'interrupteur et le moment où la baleine fait surface, déduit du contrôle, toutes les 80 ms, de la position de l'interrupteur).

TRACKING OF WHALES

Technology

NCAR (National Center for Atmospheric Research), Oregon State University and the Telonics electronics company have successfully developed a Satellite Whale Tag PTT (or SWT). The electronics is produced by Telonics of Mesa. Arizona. The first SWT was successfully deployed in July 1983.

The SWT housing is an aluminium cylinder 14 cm in diameter by 7.6 cm and weighing 3.52 kg. One end of the cylinder is attached to a flat stainless steel base plate and the other end of the housing capped with a lid using an O-ring seal. A truncated helix antenna is mounted on the lid, along with a saltwater switch contact, The lid is made of cast high-density orange polyurethane, and shaped to facilitate water run-off and give mechanical rigidity to the base of the otherwise flexible antenna. Umbrella anchors are inserted through slots in each end of the base plate. The SWT, complete with base plate and anchors, is placed on the whale's back and the anchors deployed by a specially designed applicator using electrically actuated pressure cartridges. Tags are generally fitted to entrapped whales by a crew in a small boat, the tag and applicator being suspended from a long pole.

Two sensors are used : one measures the temperature within the SWT housing the other dive duration (i.e. time from immersion of the saltwater switch to surfacing, this being achieved by interrogating the switch status every 80 ins).

The basic techniques for securing PTT-type tags to whales using subdermal umbrella anchors with curued wire tines can be considered as operational. Since 1979, such tags haue been shown to remain attached to free ranging whales for 27 months and more.

Detailed analysis of whale surfacing patterns in relation to PTT transmission specifications, satellite pass times and Service Argos requirements for satisfactory data collection and platform location resulted in the decision

Biologie-biology

Les techniques de fixation de balises par ancres sousdermales de type « parapluie » peuvent être considérées comme étant opérationnelles. Depuis 1979, il a été démontré que des balises fixées de cette façon sur des baleines en liberté peuvent rester attachées au moins 27 mois.

Des données détaillées concernant le temps passé à la surface de l'eau ont été analysées par rapport aux specifications de transmission des balises Argos, aux heures de passages des satellites, et aux exigences du Service Argos en matière de collecte de données et de localisation de balises. Cette analyse a amené l'équipe de B. Mate — et il semble qu'il s'agit d'une première pour le système Argos — à utiliser deux codes d'identitification différents pour chaque SWT et à les émettre alternativement clans des messages successifs. Un des facteurs de poids clans cette décision a été l'incompatibility entre le temps moyen qu'une baleine passe à la surface de l'eau et la specification Argos qui exige une période d'au moins 45 secondes entre deux transmissions successive avec le même code ID.

Programme 1983

Profitant du fait que, pendant les mois de juin et juillet, des baleines à bosse se font prendre de temps à autre clans des filets placés par des pêcheurs de morue et autres poissons au large de Terre Neuve, on a essayé de fixer des balises sur une ou deux baleines lors des opérations de routine pour les libérer des filets. Pendant cinq semaines d'attente, il n'a été possible de placer qu'une seule balise et malheureusement le succès de cette opération a été partiel. En effet, suite au fonctionnement défectueux des cartouches, normalement fort fiables, de l'applicateur, les ancres sousdermales n'ont été déployées que partiellement. On a envisagé la possibility d'enlever, puis de refixer la balise, mais cela comportait trop de risques pour l'équipage. Néanmoins, il y a eu une bonne réception de données pendant 144 heures et on suppose que la balise s'est détachée par la suite. Pendant cette période, la baleine a parcouru plus de 700 km, à une vitesse moyenne de 6 km/h, tandis que la balise a fourni une quantité importance de données concernant la température de l'eau et la durée des plongées. L'analyse de ces données a permis aux chercheurs d'arriver à des conclusions biologiques tout à fait significatives.

Quelques unes de ces conclusions peuvent être sommairement résumées ainsi :

- des plongées tongues ne sent pas forcément des plongées profondes;
- les baleines plongent en quête de nourriture ou plus généralement, ont tendance à localiser leurs activités clans des masses d'eau délimitées par une ou plusieurs thermoclines:
- bien que les données disponibles soient insuffisantes, il semble bien que des plongées de durée plus ou moins longue prédominent à certaines heures de la journée;
- il semble aussi que des changements de la durée des plongées en fonction de l'heure soient en rapport avec la nature cyclique de la quête de nourriture, les stratégies changeantes de quête de nourriture et le comportment des espèces chassées par la baleine.

Programmed futurs

Des études sent en tours sur une adaptation de l'interrupteur déclenché par l'eau de mer qui perrnettrait de déterminer la salinité à partir de la mesure de la conductivité de l'eau, de la température et de la pression. Il semble même tout à fait possible d'envisager une balise capable de fournir des profils de pression, de température et de salinité lors de plongées successive. La collecte de données d'un tel intérêt océanologique contribuerait à améliorer nos connaissances générales des différentes masses d'eau des océans tout en offrant la possibility de nous apprendre beaucoup sur les baleines, leur comportment général, leur comportment en plongée, leurs habitudes de quête de nourriture, et aussi leurs moyens de navigation. Mais, la grande difficulté avec la collecte de telles quantités de données reste la limitation, imposée par le système Argos, à seulement 32 octets de données utiles par message émis.

Lors du programme 1983 il n'avait pas été possible d'obtenir des données de localisation du Service Argos parce que les taux de transmission de messages étaient incompatibles avec les logiciels de traitement.

Avant même que ce rapport ne soit lu par les lecteurs d'Argos Newsletter, il est probable que deux balises SWT aient déjà été fixées sur des baleines grises du Pacifique au large de Baja Califomie, Mexico; ce travail ayant été programmé pour la saison (mi-janvier à la fin février) à laquelle les baleines grises sent clans ces eaux-là. Ce sera un test important des qualités de résistance des SWT. Line de ces balises sera du type décrit plus haut tandis que la deuxième bénéficiera de nouveaux moyens denregistrement des profils de plongée. Ce sera la première fois qu'une balise de collecte de données par satellite sera employée pour l'analyse en trois dimensions des movements et du comportement des baleines.

Résumé par le Service Argos
de la présentation de M. B. Mate
à la conférence Argos de Londres (1983)

— and, to our knowledge, a first for the Argos system — to use two different ID numbers for each SWT, and to alternate the IDs encoded into successive messages. A factor of particular importance in this decision was the incompatibility between typical whale surfacing times and the Seruice Argos requirement that transmissions using the same ID code be separated by at least 45 seconds.

1983 Program

Taking advantage of the fact that, during June and July, humpback whales occasionally become entangled in gillnets and cod nets off Newfoundland it was decided to tag one or two as part of the routine release operations. A five-week wait only prouided one opportunity for tagging. Unfortunately, this was not fully successful as poor performance of the normally reliable pressure cartridges (of the tag applicator) resulted in incomplete deployment of the subdermal umbrella anchors. Removal and re-application were considered, but deemed too dangerous. Nevertheless, good data were receiued ouer a period of 144 hours after which, it is assumed, the tag fell of. During this time the whale traveled ouer 700 km, at an average speed of about 6 km/h while the SWT returned much useful temperature and diue duration data enabling the investigators to make several significant biological findings. Some of these findings can be very briefly summarized as follows:

- *long dives are not necessarily deep dives;*
- *whales often feed and generally concentrate their activity in waters bounded by one or more thermoclines;*
- *although the information is scant, there appear to be times of the day when longer and shorter dives are more prevalent;*
- *changes in diving patterns with time of day may, in turn, be related to feeding cycles and strategies and also to prey behaviour.*

Future Programs

Work is currently in hand on adapting the salt water switch to determine water conductivity, which can then be related to salinity following temperature and pressure correction. in fact, it seems quite feasible to envisage a PTT-type whale tag capable of profiling pressure, temperature and salinity throughout successive dives. The acquisition of such valuable oceanographic data would increase our knowledge of ocean water masses in general and potentially tell us a great deal about whale

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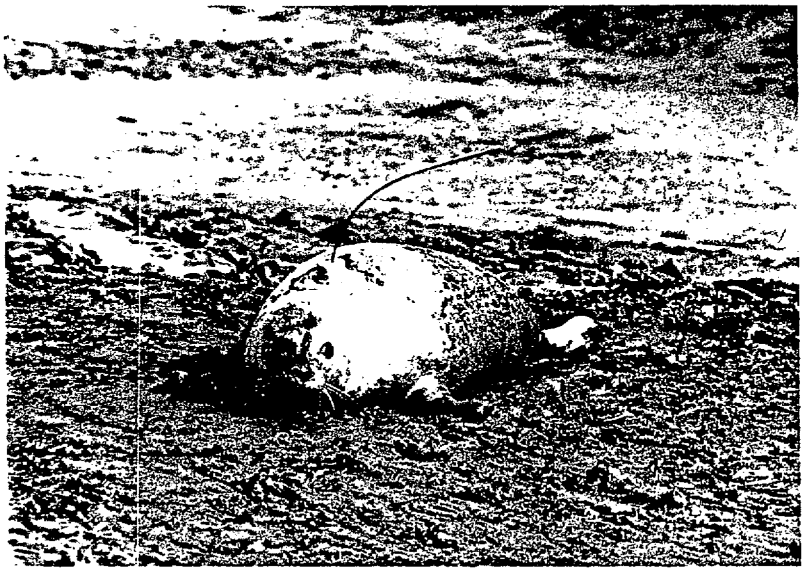
' behavior, diving, and foraging patterns, not to mention their navigation skills.

However, the principal problem with acquiring such quantities of data is the Argos limitation of only 32 eight-bit words during each transmission.

During the 1983 program it was not possible to obtain location data from Service Argos because the message transmission rates were incompatible with the Argos processing software. By the time this article appears in the Argos Newsletter, Bruce Mate and his team should haue applied two SWTs to gray whales off Baja California, Mexico, this work having been scheduled for the mid-January through end-February (1984) field season in that area. This will be an important test of SWT endurance. One SWT will be of the type described, the other will incorporate new dive profiling features. This experiment represents the first satellite monitored instrumentation to give a three-dimensional analysis of whale movements and behavior.

Summary by Service Argos of the paper read by Mr B. Mate of the 1983 Argos Conference

LE SUIVI DES MAMMIFÈRES MARINS



Émetteur VHF fixé à la fourrure dun phoque commun
VHF transmitter attached to the fur of a common seal

Les phoques et les baleines suscitent à la fois un grand intérêt et de vives controversies parmi les défenseurs de la nature, les industries de la pêche et de la baleine et les gouvernements nationaux.

Le Groupe de Recherche sur les Mammifères Matins qui fait partie du Conseil de la Recherche sur le Milieu Naturel du Royaume Uni participe a de nombreux projets visant essentiellement a foumir des information sur la population et la répartition des phoques et des baleines ainsi que sur leur interaction avec leur environnement marin.

Il est en particulier nécessaire de connaitre la repartition clans l'espace et clans le temps de ces animaux, leurs habitudes alimentaires et l'identité des banes de poissons pour déterminer leur importance numérique, prévoir les effets probabies résultant de la chasse et des eliminations rationnelles et évaluer les effets de ces mammifères marins sur les banes de poissons en tant que concurrent potentials des pêcheurs.

Pour des animaux tels que les phoques ou [es baleines qui ne peuvent être observés directement que pendant des laps de temps très courts ou après qu'il aient été tués ou capturés, il est essentiel de disposer dune technique s'apparentant plus ou moins à la télédétection ou à la télémesure.

Toutefois, ces mammifères posent des problèmes particuliers pour la télémétrie car ils sent difficiles a capturer et à équiper d'un émetteur et ils peuvent parcourir des zones très vastes.

En outre, il ne faut pas perdre de vue les problèmes habituels liés au travail en mer, [es effets d'une immersion en eau salée, les variations de pressions et la difficulté d'une transmission d'information à travers l'eau de mer. Les phoques posent des problèmes uniques en ce qui concerne [a fixation de dispositifs de mesure. Du fait de leur forme hydrodynamique et de l'absence de resserrement au niveau du cou ou de la queue, le bracelet ou le collier s'avèrent être des dispositifs peu pratiques.

[1s ont heureusement une fourrure résistante qu'ils perdent chaque année en période de mue. On peut done simplement et efficacement fixer des émetteurs à même le poil de l'animal au moyen de cone Epoxy à prise rapide.

Cette cone est facile à appliquer et l'on est srir que l'ensemble sera abandonné l'année suivante lors de la mue.

Notre première tentative de localisation de phoques par télémétrie radio remonte à la saison des amours d'octobre 1982. Au total ce sent 30 émetteurs-radio de 173 MHz disposant chacun dune portée de 20 miles qui ont été fixés sur des phoques se trouvant sur leur aire de reproduction en Ecosse. On a d'abord suivi ces animaux a l'aide de récepteurs installés sur des avions. Toutefois il est très vite apparu que cette façon de procéder était lourdement pénalisée par le coût, le temps de recherche important et l'autonomic limitée de ces appareils. D'où notre intérêt pour un émetteur capable de relayer les information par satellite.

La capture des phoques présente peu de problèmes inhabituels. Cependant, ces animaux étant d'excellents nageurs et leur taille n'étant pas tres grande, une électronique de dimensions réduites et aussi peu apparente que possible est nécessaire.

Les baleines présentent encore d'autres problèmes.

Du fait de leur taille immense, la conception et l'encombrement de la plate-forme sent moins critiques. La capture de ces animaux, le moyen de fixation de la plate-forme, l'encombrement de cette dernière, le fait qu'ils parcourent les océans du monde entier et qu'ils ont rarement besoin de se rapprocher des totes, constituent des défis difficiles à relever.

La technique de fixation de la plate-forme que nous avons essayé résulte de la constatation que le petit harpon manuel, utilisé par les baleiniers, a bord de leur embarkation ouverte

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clans les Açores, était parfois retrouvé un an, voire plusieurs années après que la baleine ait réussi a échapper aux chasseurs. Le harpon n'est en fait utilisé que pour retenir la baleine et ne sert pas à la mise à mort. Il semblerait qu'il ne provoque que des lésions mineures des tissus.

Bien que l'activité soit réduite, la chasse du cachalot se poursuit encore clans les Açores, mais nous devrions etre en mesure ces dew. prochains étés de convaincre des baleiniers expérimentés de nous laisser équiper un animal dun émetteur Argos. Les équipages et embarkations d'origine demeurent disponibles pour fixer les plates-formes sur les baleines. Cette opération est réalisée en ramant. l'embarkation devant etre amenée aussi près que possible de l'arrière de la baleine se reposant après une plongée en eau profonde.

Un harpon manuel a été conçu pour fixer la plate-forme. Il est réalisé à partir de matériaux non sujets à la corrosion et non-toxiques. La plate-forme est contenue clans un boitier sphérique en verre pour instrument océanographique et rattachée au harpon a l'aide d'un filin. La sphère est équipée dun lest. Il est ainsi possible de régler sa flotaison et sa position à la surface de l'eau.

Le Système Argos constitue une alternative possible et rentable à la télémesure radio conventionnellement utilisée pour les phoques et les baleines. San efficacité est fonction a la fois de la méthode de capture, de la technique de fixation du matériel et de la possibilité de disposer dun émetteur et dune antenne petits, robustes et de faible consummation.

On cherche actuellement a obtenir la certification Argos pour un tel émetteur.

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MARINE MAMMAL TRACKING

Seals and whales are the focus of much interest and controversy for conservationists, the fishing and whaling industry, and national governments. The Sea Mammal Research Unit, part of the United Kingdom's Natural Environment Research Council, is involved in a number of projects whose overall aim is to provide information on the numbers and distribution of seals and whales and their interaction with the environment. In particular, knowledge of temporal and spatial distribution, feeding patterns and stock identity are needed to determine population size. This information is used to predict the likely effects of hunting and management culls. and to estimate the efects of the marine mammals themselves on fish stocks as potential competitors with fishermen.

For animals such as seals and whales which can only be observed direct/g for a very small fraction of the time, or after they are captured or killed, some sort of remote sensing technique or telemetry is essential. However, marine mammals present particular problems for telemetry because of difficulty of capture and transmitter attachment, and the vast ranges over which they may travel.

In addition there are the obvious problems of working at sea and the effects of salt water immersion, pressure changes and the difficulty of transmitting information through sea water. Seals present unique problems for attachment of any sort of measuring device. Their streamlined shape and lack of constrictions at the neck or ankle make a collar or bracelet impracticable However their fur is strong and is moulted once each year, and transmitters can be attached simply and efficiently using a fast-setting epoxy glue and attaching the package direct/y to the hair. This is easy to apply and has [he advantage that the package will certainly be shed at the annual moult.

Our first major attempt to track seals using radio telemetry started during [he 1982 breeding season in October. A total of thirty MHz radio transmitted, each with a 20-mile range, were attached to seals at their breeding sites in Scotland, The seals were tracked primarily using receivers fitted to aeroplanes. However it became obvious that this method of following seals was severely lim ited by the expense, unequal search effort and geographical range of the aeroplanes. Therefore we looked into the possibility of using which could relay information via a satellite.

The capture of seals presents few unusual problems. However, since they are active swimmers and not overly large the package size must be kept small with as low a profile as possible.

Whales present still other problems. Because they are large. package size and design are less critical. Capture. attachment. their global range and the fact that the animals need never come near land present the greatest challenges. The attachment technique that we have tried was suggested by the discovery that the small hand-thrown harpoon used by open-boat whalers in the Azores Isla nds were sometimes found in place on a whale one or more gears after it had escaped the hunters. The harpoons are merely used by the whalers to hold the whale, not to kill it, and appear to cause no sign ificant tissue damage.

The Azores sperm whale fishery is continuing at a low level of activity but, over the next two summers, we should be able to divert the hunters' skills from killing their animals to providing us with a sample of sperm whales with their own personal Argos PTT. Original crews and boats remain available to place the attachment in the whale. This involves paddling a small boat almost onto the back of a whale while it is resting after a deep dive.

For the attachment a miniature harpoon has been designed from non-toxic. non-corroding materials, The PTT is housed in a spherical oceanography ic glass instrument housing and is attached by a length of steel cable to the harpoon. The sphere is weighted to adjust its buoyancy and to control its attitude when afloat

The Argos satellite system provides a feasible. cost-effective alternative to conventional radio telemetry for both seals and whales. Its usefulness depends both on successful capture and attachment techniques and robust, small transmitters and aerials which have low power requirements. Type approval is currently being sought from Argos for such a transmitter disign.

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ARGOS LOCALISE UN REQUIN

Le 22 juin 1982, l'aube était calme et claire au-dessus de l'estuaire de Firth of Clyde, ce bras de mer sur la côte Ouest de l'Ecosse.

Deux étudiants, un technician et moi-même étions à bord dun bateau à moteur que nous avions affrété. Nous avons appareillé clans le port pittoresque de East of Loch Tarbet à la recherche dun requin pélerin.

Nous avions à bord la balise Argos destinée à équiper l'un de ces poissons géants.

C'est en 1981 que cette balise a été construite mais les requins ont été si rares cette année là que nous n'avons pas pu nous rapprocher suffisamment de l'un d'entre eux pour accomplir notre mission.

Nous remorquions une petite embarkation devant servir à la fixation de la balise sur le requin. Le cap fut mis au Sud sur l'Ile d'Arran où nous attendait une équipe de télévision que nous devions prendre à bord et qui réalisait un reportage sur notre travail.

La mer était calme permettant ainsi un meilleur repérage des requins. Très vite l'un d'entre eux apparut, sa nageoire dorsale fendant la surface de l'eau. Puis un autre fut observé : les requins pélerins étaient de retour. Tous étaient de petite taille, n'excédant pas 2 à 3 mètres. Ils étaient done trop petits pour notre balise. Celle-ci, destinée a être fixée sur [e requin, a la forme d'une capsule flottante (Fig. 1) trainée au bout dune ligne de traction attachée à un point d'ancrage enfoncé à la base de la nageoire dorsale.

Ce que nous recherchions est alors apparu: un bel adulte de 7 mètres, nageant presque en surface; sa gueule largement ouverte filtrant une grande quantité d'eau pour ne retenir que les particles microscopiques de plancton. Fallait-il prévenir l'équipe de télévision avant de fixer la balise sur le requin ? Non, nous n'avions en aucun cas l'intention de laisser s'échapper la plus belle chance s'offrant à nous depuis deux ans !

Deux d'entre nous ont alors sauté clans la petite embarkation à moteur et se sont rapprochés de l'arrière du requin, celui-ci ignorant totalement notre présence. Tout était prêt : je tenais le harpon permettant de fixer la ligne de traction, la balise était sur le point d'être jetée par dessus bord.

En 1978, lors d'une première tentative, un requin avait fait chavirer notre chaloupe d'un coup de queue et nous nous étions tous retrouvés à la mer. Qu'allait-il se passer cette fois-ci ? Notre manœuvre minutieusement répétée s'avère réglée à la perfection. J'enfonce le point d'ancrage, la bobine de fil de traction passe par dessus bord (Fig. 2) suivie de la balise et le requin amorce alors une plongée saris le moindre incident.

C'est ainsi qu'eût lieu la première localisation réussie dun poisson au moyen du Système Argos.

C'était l'aboutissement de quatre années d'efforts. Nous nous sommes alors dirigés vers l'équipe de télévision, furieuse de n'avoir pu enregistrer cet événement mémorable, mais nous avons pu leur en montrer d'autres le jour même.

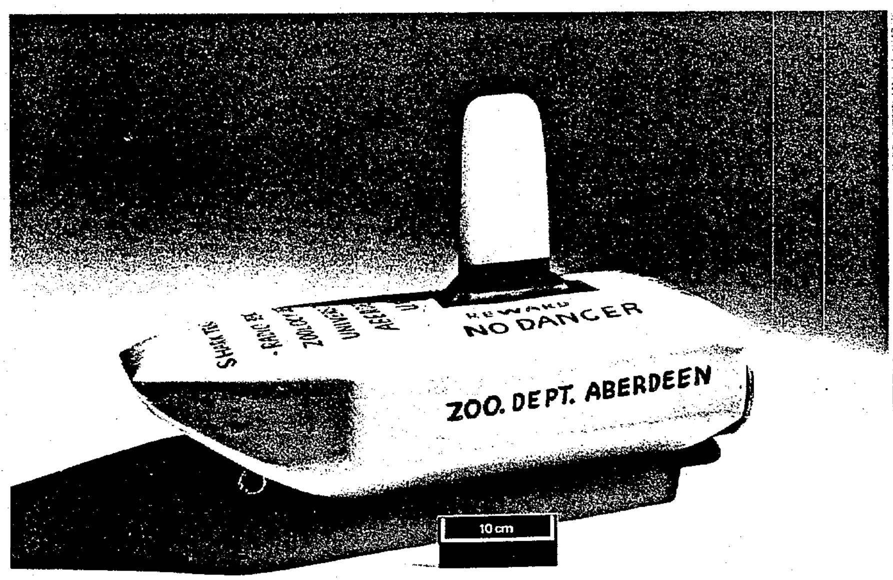

Figure 1: Balise Argos pour requins pélerins.
Antenne quart d'onde incorporée clans l'ailette verticale en polyéthilène et un manocontact mettant le dispositif hors-tension quand ce dernier est immergé.

Figure I: Argos PTT for basking sharks. A quarter wave antenna is incorporated in the polyethylene vertical fin. A pressure switch inactivates the device when submerged.

A peine ces exploits étaient-ils terminés qu'un temps pluvieux s'est installé et aucun autre requin n'a plus été observé. Le 2 juillet, le requin a été localisé pour la première fois par Argos 55 km plus au sud. D'autres localisations ont été effectuées les 3 et 5 juillet. Le 6, les nuages se sent dissipés et le requin a été suivi à vue pendant pratiquement toute la journée. Nous avons surveillé la surface de la mer en utilisant des images par satellites CZCS de NIMBUS et AVHRR de NOAA 7 ainsi que la station ternenne de satellite de l'Université de Dundee.

Cette image a été obtenue à 14.36 GMT tandis que le système Argos recevait les émissions de la balise du requin.

Après le 6 juillet, le temps est redevenu maussade et nuageux. Le requin n'a pratiquement plus refait surface, se déplaçant clans la zone de Clyde jusqu'au 14 juillet, date à laquelle la ligne de traction s'est détachée. La balise a été localisée par Argos lors de sa dérive et a été finalement recueillie par un homme se promenant avec son chien. La balise Argos a été renvoyée à Aberdeen en parfait état de marche.

La possibilité de localiser les animaux marins au moyen d'un système Argos a ainsi été clairement démontrée. Les localisations d'Argos renseignent sur le comportment animal, le requin demeurant en surface par beau temps ensoleillé et disparaissant clans les profondeurs de la mer les jours pluvieux et maussades.

Ces observations correspondent bien à celles qui ont été faites sur le comportment du requin pélerin. Le 6 juillet les localisations ont été suffisamment nombreuses pour permettre le calcul de la vitesse de nage du requin et la comparison de cette dernière aux prévisions de recherche de nourriture théorique optimale.

L'obtention à la même date de la localisation et d'images satellite a

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constitué une mise au point passionnante. Pour nous, il s'agit là dun outil des plus puissants car la télédétection permet de repérer les fronts thermiques ainsi que la production primaire et la chlorophyll.

La comprehension des déplacements et du comportment des plantivores lors de la recherche de nourriture par rapport aux caractéristiques océanographiques est fondamentale. Elle permet d'améliorer notre connaissance de la dynamique de la chaine alimentaire marine.

La perte de la balise. 17 jours plus tard s'est avérée décevante car la batterie a une durée de vie de 110 jours et d'autres balises endommagées sent précédemment demeurées en place pendant trois mois.

La durée de l'expérience démontre néanmoins [e caractère rentable d'une localisation par satellite par rapport au temps qu'il faut à un navire pour mener à bien une telle surveillance au moyen de techniques conventionnelles.

Des systèmes VHF ou sonar embarqués sur navire ne pourraient pas repérer plus d'un seul Poisson à la fois.

Les efforts portent actuellement sur l'élaboration d'une balise moins volumineuse pouvant être fixée sur des animaux plus petits pendant des périodes beaucoup plus longues.

Un rapport détaillé sur ces travaux est actuellement publié clans • Fisheries Research., Elsevier, Amsterdam. Le film sur les requins pélerins est produit par Walt Deas, Sea West Productions, 8 Arkana Place, Engadine. N.S.W., Australie.

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ARGOS TRACKS A SHARK

The dawn of 27th June, 1982 was bright and calm on the Firth of Clyde. a great inlet of the sea o n the West Coast of Scotland, Two students. a technician and I set out from the picturesque port of East Loch Tarbet on board our chartered motor yacht in search of a basking shark We had on board an Argos PTT which we were going to attach to one of these giant fish. The PTT had been built in 1981. but in that gear so few sharks appeared that we had no opportunity to get close enough to one. This gear was our last chance: we had been working on the development of a satellite tracking technique since 1978 and funding was running out.

We were towing a dory which was to be used for the actual tagging of the shark. We turned South and headed to the Island of Arran to pick up a film crew who were making a TV film about our work. The water was smooth and idea/ for spotting sharks. Soon we saw one, the fin cuttin g the surface. and then another: the basking sharks were back ! They were all young ones only 2 or 3 metres long, too small for our PTT. The shark PTT takes the form of a buoyant capsule (Fig. 1) which is towed by the animal with a line attached to an anchor injected into the base of the dorsal fin. We then spotted what we were looking for. a nice 7 m long adult swimming along near the surface: its mouth was wide open taking in vast amounts of water and filtering out the microscopic planktonic food particles. Should we go and fetch the TV crew before tagging this shark ? No, this was the best chance we had had for two years and was not to be missed.

Two of us leapt into the dory and motored carefully up behind the shark which was oblivious to our presence. I had a hand harpoon ready for imbedding the tow line anchor. the PTT was ready to throw overboard. In one of our early attempts at this in 1978 a shark had lifted our boat with its tail and thrown us into the water. What could happen this time ? Our carefully rehearsed manœuver was perfectly timed. 1 injected the anchor, the coil of line went overboard (Fig. 2). then the PTT, the shark submerged with no drama at all.

Thus began the first successful track of a fish using the Argos System; the culmination of four years of development work. We went on to meet the film crew who were furious at not having recorded the great event. but we were able to show them other sharks later in the day.

Short/g after these exploits a period of cloudy rainy weather set in and no sharks were seen on the surface. Argos first located the tagged shark on the surface five days later some 55 km further South on 2nd. July. Further locations were recorded on 3rd and 5th July, and then on 6th July the clouds cleared and the shark was tracked on the surface for most of the day; seven successive locations being achieved by Service Argos. We monitored the sea surface by satellite remote sensing, using the nimbus CZCS and NOAA 7 AVHRR with the help of the University of Dundee satellite ground station in Scotland.

After 6th July the weather reverted

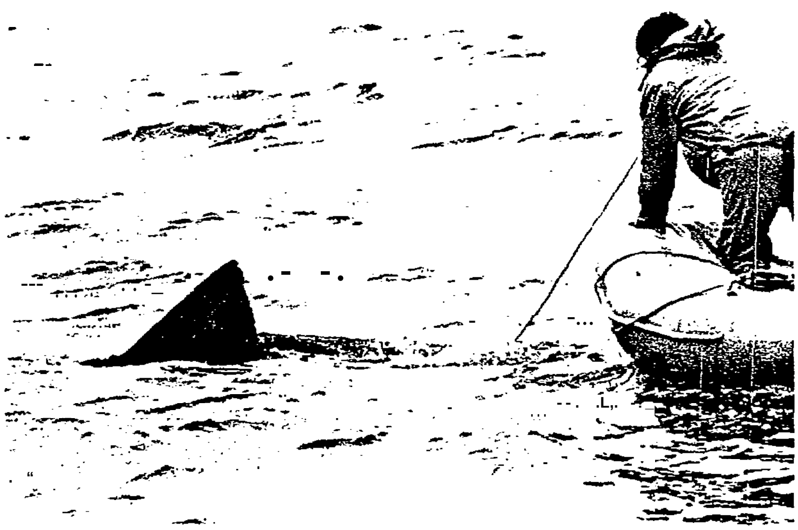

figure 2: Déroulement de la ligne de traction fixée sur le requin. Une bonne synchronisation des operations est essentielle.

Figure 2. Tow line being paid out after attachment to the shark Good timing is essential.

to dull cloudy conditions and the shark only surfaced sporadically, moving within the Clyde area until 14th July when the PTT tow line parted and Argos tracked the capsule as it drifted towards the shore and was eventually picked up by a man walking on the beach with "his dog. The PTT was returned to Aberdeen in good working order.

The feasibility of tracking marine animals using the Argos system has been clearly demonstrated. The pattern of location by Argos tells us something about the behaviour of the animal in that it was on the surface during clear sunny weather and remained deeper on dull rainy days. This accords well with general observations of basking shark behaviour. On 6th July sufficient locations were obtained to calculate swimming speeds for comparison with predictions of optimal foraging theory. The most exciting development was the achievement of simultaneous tracking and remote sensing imagery. This we see as a most powerful tool, since through remote sensing thermal fronts can be detected together with chlorophyll and primary production. An understanding of the movements and foraging behaviour of planktivors in relation to these oceanographic features is of fundamental importance in advancing our understanding of marine food chain dynamics.

The shedding of the PTT after only 17 days was disappointing (battery life 110 days), previous damaged PTTs have remained attached for 3 months. The duration of the track nevertheless proves the cost effectiveness of satellite tracking when compared with ship time necessary to sustain such an exercise using conventional techniques. Ship based sonar or VHF systems could not track more than one fish at a time.

At present work is directed towards a smaller PTT package which could be attached to smaller animals and also remain attached for much longer periods of time.

A full report of this work is being published in "Fisheries Research", Elsevier, Amsterdam. The film on basking sharks is being produced by Wa tiDeas, Sea West Productions, 8 Arkana Place. Engadine. N.S. W.. Australia.

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SUIVI DE TORTUES LUTHS

Les tortues Luths (Dermochelys coriacea, Vand.) sont des animaux pélagiques dont nous commençons seulement depuis quelques années à bien connaitre les habitudes lorsqu'elles s'approchent des côtes pour la ponte ou par le fait des courants. Ces activités littorales ne représentent qu'une phase minime du cycle de vie de ces tortues, et encore intéresse-t-il essentiellement les femelles. C'est ainsi que des observations de l'espèce sont faites par nous chaque année sur le site le plus important de ponte localisé au PLO. de la Guyane et clans la région des Pertuis charentais (S.0. de la France) où l'activité est surtout alimentaire.

Des milliers de femelles ont été marquées avec des bagues numérotées en Guyane et au Surinam, avec un très faible pourcentage de « recaptures ». A l'exception dune Luth revue au Ghana (Pritchard, 1976), les autres ont été retrouvées au Venezuela et le long des côtes des U.S.A. De nombreuses observations ont été faites très au nerd jusque vers Terre-Neuve, la Nouvelle Angleterre et la Nouvelle-Ecosse (Bleakney, 1965). Étant donné que les lieux de ponte en Afrique de l'ouest et en Méditerranée sent très restraints, il est done probable que la plupart des femelles rencontrées sur les côtes européennes et africaines aillent pondre sur les plages guyanaises ou sur celles des différents petits sites des Caraïbes. S'agit-il dune véritable migration à travers l'océan en suivant tel ou tel courant, d'erratisme de certaines tortues ou bien d'une dispersion de la grosse colonie reproductrice de Guyane en petits groupes de quelques individus ?

Cest pour tenter de répondre à cette question que nous avons entrepris un programme de suivi des Luths nidifiant en Guyane ou passant le long des côtes de France, à l'aide du Système Argos.

Diverses expérimentations de suivi de tortues marines ont été faites, soit à l'aide de ballons météo, soit par radio ou sonic tracking. Ces suivis chez Chelonia mydas, Lepidochelys kempii, Caretta caretta et D. coriacea, n'ont été entrepris que sur de courtes distances et ne renseignent pas sur les « routes océaniques ».

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TRACKING OF LEATHERBACK TURTLES

Leatherback turtles (Dermochelys coriacea, Vand.) are deepsea reptiles that are known to approach the coast to lay eggs or, involuntarily, because of the effect of the current, Only recently, however, have we gained any real insights into their habits.

Although coastal. activity represents only a small part of the animal's life cycle, and is restricted to females, these periods enable us to make annual observations at two sites, The first is the most important local nesting site, located in North-west French Guiana, while the second site is in the Charentais Straits (France.), where feeding is the main activity.

A previous program involving the ringing of several thousand females in French Guiana and Surinam resulted in a very low percentage of subjects being retrieued on the other side of the Atlantic. Excepting one leatherback sighted in Ghana (Pritchard, 1976), all the ringed animals turned up in Venezuela and along the North American coast. More generally, many sightings have been reported as far to the North as Newfoundland, New England and Nova Scotia (Bleakney, 1965). Given that laying sites in West Africa and the Mediterranean are few and far between, it seems likely that most of the females found on the European and African coasts lay their eggs on the beaches of French Guiana or those of the various smaller sites of the Caribbean. The question now is to determine whether there is true

Biologie-biology

transatlantic migration of the species via some ocean current or rather wandering of individuals. or, a third hypothesis, the scattering of a large reproducing colony into small groups.

It was to find an answer to this question that we conducted an Argos-based program to track leatherback turtles nesting in French Guiana or moving along the coast of continental France.

A number of experiments have already been performed, using either weather balloons, or radio or sonic tracking. These programs, however, concerning **Chelonia mydas** (green turtle), **Lepidochelys kempii** (Ridley), **Caretta caretta** (Loggerhead), and **Dermochelys coriacea** were only undertaken over short distances and therefore do not yield information as to ocean routes.

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cherchant a couvrir toute la durée d'une migration éventuelle. Là, les délais de restitution des données de l'ordre de quelques heures seront admissible. La mise en fonctionnement de l'électronique sera espacée vraisemblablement pour une cadence de 1 fois tous les 15 jours. Une localisation très précise, calculée au moins à partir des mesures faites au tours de deux passages de satellite, devrait suffire.

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Suivi de Luths femelles à partir de la Guyane
- protocole expérimental

Cette expérimentation consiste à suivre une Luth femelle équipée d'une balise Argos à partir de la plage de ponte des Hattes (region frontalière avec le Surinam) où est situé le camp de base, Le protocole comporte plusieurs phases:

1) etude de la fixation de la balise sur la tortue avec essais à terre;
2) essais de la selle de fixation et de l'électronique en mer:
3) lancement de l'électronique;
4) suivi sur plusieurs années;
5) récupération de l'électronique. fin de l'expérimentation.

La phase 1 a été réalisée d'avril a juin 1983 avec la mise au point dun premier modèle de selle conçu pour recevoir une plate-forme de localisation CML 80; cette selle sera modifiée en 1984 et testée en mer avec un émetteur. Elle comprend une armature de résine (réserve de flottabilité) sur laquelle vient se fixer le socle de la balise (visserie inox), un tapis isolant antimycosique et un hamais.

Les prochains essais devront définir la fréquence des localisations en fonction de la qualité des émissions, des temps de surface de la tortue, de la durée de fonctionnement du bloc alimentation. En effet, en plus d'une antenne omnidirectionnelle et de l'électronique. un bloc alimentation composé de piles au lithium est incorporé clans le boitier de la plate forme émettrice. En raison de contraintes de poids et d'encombrement, pour l'expérimentation clans son ensemble, une alimentation par cellules photovoltaïques conviendrait mieux a nos besoins sur plusieurs années.

La première partie du programme s'apparente à une période d'essais propre à la saison de ponte des tortues Luths. Chaque femelle revient pondre jusqu'à 7 fois de suite à une dizaine de jours d'intervalle. Des contacts visuels en mer et des interventions à terre nous permettront d'évaluer son comportement, son état physique et de s'assurer de la bonne tenue du matériel, ainsi que son acceptation par l'animal.

Pour ces interventions, la restitution des données de localisation de la plate-forme nous donnera une position journalière, complétée en temps réel par une réception directe radio-gonio-métrique. Ces essais préliminaires nous renseigneront sur les déplacements entre chaque ponte de la tortue équipée, sur la sortie éventuelle des eaux guyanaises et la fidélité ou non a une plage.

Le lancement de l'électronique interviendra done à l'issue de ces essais. Cette seconde partie du programme annoncera le debut de l'expérimentation sur plusieurs années

*Tracking female **Leatherbacks** from French Guyana*
- experiment procedure

This experiment consists in the tracking of a female leatherback turtle carrying an Argos PTT, starting from the laying site on the beach at Les Hattes (French Guiana. near the border with Surinam) where our base camp was originally situated.

The experiment involves several phases:
1) studies into the most suitable method of fixing the PTT to the turtle, followed by land trials:

2) *sea trials of the fixing assembly and electronics;*
3) *switching on the PTT;*
4) *tracking ouer a period of several years;*
5) *PTT retrieval: this will mark the 'end of the experimental phase.*

Phase 1 took place *between April and June 1983, and gaue rise to a* unit *designed to accommodate the CML-80 location-type PTT. The unit is now being modified, and is undergoing sea* trials *with* a *liue transmitter. It consists of a resin shell which acts* as *a float, and on which is mounted the* base *of the PTT with stainless steel fittings, an anti-fungal insulating pad, and a harness.*

The next batch of trials will serue to *define* the *frequency of locations* as *a function of transmission quality,* surfacing *time of the turtle, and lifetime of the power supplies. The omnidirectional antenna, electronics and lithium batteries* are *all housed within the PTT unit. However, given the weight and volume constraints, and* the *fact* that the experiment is to continue over a number of yars, *solar cells would be* a *more efficient power source.*

The first stage of the program coincided with the laying period. Females return to the laying site on up to seuen occasions, *at* approximately *ten-day interuals. Visual sightings at sea and on land yielded an opportunity for assessment of the behauior and physical condition of the subject, as well as monitoring the state of the hardware and the* degree *of acceptance by the animal.*

Between uisual sightings, location data giue us a daily position fix, complemented by real-time direction finder fixes. These preliminary trials giue us *information as* to *mouement between each laying,* point *of exit from the* area, and any *preference for a particular beach.*

At the end of these trials, the PTT was turned on. *This was the beginning of a multi-year experiment using Argos, the aim being to couer the entire migration cycle (if, indeed, such migration* occurs). For this *work, we* can *accept* an *internal of a few* hours before data *become auailable. The electronics will probably switch on once every two weeks. Accurate location based on measurements made during at least two satellite passes should be sufficient*

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Harnais pour tortues Luth

La réalisation technique au Museum d'Histoire Naturelle de La Rochelle d'un harnais maintenant une balise Argos sur Dermochelys coriacea, s'inscrit clans la phase préliminaire de l'étude du suivi par satellite des tortues Luth err Atlantique.

Le projet consiste à munir dune balise Argos type transat spécifiquement adaptée pendant un cycle annuel, cinq individus en Guyane française (lieu de nidification) et trois clans les Pertuis charentais (lieu de fréquentation estivale).

Il a pour but de dormer des éléments objectifs en faveur d'une véritable migration transatJantique ou d'une dispersion d'individus erratiques à partir des courants transocéaniques (cf.: conférence Utilisateurs-Argos Paris 21 avril 1982).

Rappel: 1° La tortue Luth Dermochelys coriacea se distingue des autres Chelonioïdea par l'absence d'écailles sur sa dossière carênée, par sa taille : la longueur maximum atteint 2,40 m, pr son poids estimé entre 350 et 600 kg.

2° Un premier repérage par radio à antennes directionnelles a été pratiqué en 1978 clans les Pertuis Charentais (M. Duron, 1978). La technique de maintenance de l'émetteur exposé clans Argos Newsletter 1981 no 11, a été à l'origine de la réalisation du harnais présentement décrit.

Le harnais

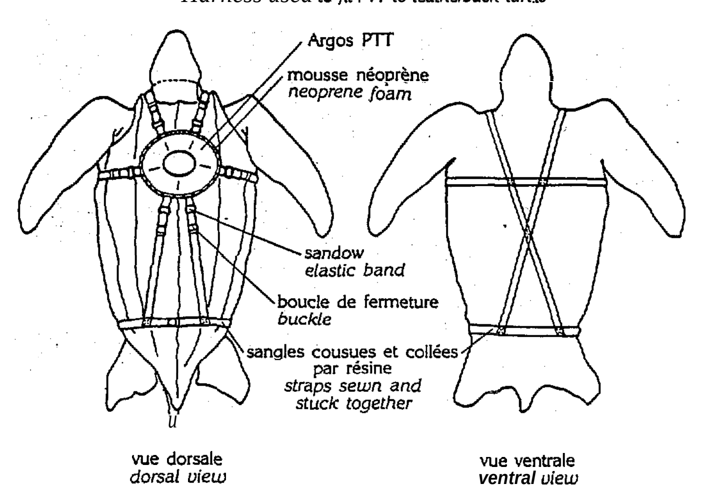
Le harnais doit maintenir une balise Argos clans la partie antéro-supérieure médiane de la carapace afin de libérer l'émission de la plate-forme lors de l'émersion partielle de l'animal pendant ses phases de respiration et de déglutition.

Plusieurs impératifs ont été respectés pour sa réalisation :

- robustesse: il doit résister pendant un cycle annuel à la corrosion marine et aux forces hydrodynamiques rencontrées ;
- simplicité : les conditions extrêmement précaires de la plage des Hattes (Guyane Française) rendent nécessaire d'éviter les manipulations sophistiquées et de prévoir un maniement simple avec des attaches rapides et légères;
- rapidité : le temps de manipulation ne doit pas excéder 1 h 30 mn (temps d'émersion totale pour la nidification) de manière à ne pas perturber le comportment de l'animal choisi;
- conformité avec la physiologic de l'animal : l'interface placée entre la balise et la dossière de la tortue doit respecter les échanges biologiques et être réduite au minimum afin de laisser la respiration cutanée se rapprocher de la normale. Toutes causes de blessures doivent être évitées.

Ainsi tenant compte de ces différents paramètres, le harnais se compose d'un assemblage approprié de six sangles de nylon tressé de 5 cm de largeur cousues entre elles. Elles entrent clans les six fentes spécialement disposées sur un cercle inox entourant la balise avant de se boucler respectivement. Un sandow disposé sur chaque sangle apporte une élasticité au moment du sanglage et tout au long de l'experience. Un bracelet de mousse néoprène enveloppe chaque boucle

Schéma du harnais maintenant une balise Argos
Harness used to fit PTT to leatherback turtle



de manière à protéger la carapace des frottements éventuels. Les sangles croisées sous le plastrom se referment sur la dossière en convergent vers la balise.

Le harnais est adaptable a n'importe quelle tortue Luth adulte.

L'interface

L'interface balise-tortue permet de rendre solidaire l'enveloppe inférieure exteme de la balise Argos à surface plate avec la dossière carênée de la tortue, tout en respectant les échanges biologiques de l'animal.

Formée par un empilement cylindrique de douze disques (diamètre 42 cm - hauteur 8 cm) de mousse néoprène collés entre eux, elle est fendue en son diamètre sagittal pour laisser se loger la carêne médiane de la dossière de l'animal. L'adaptation finale des coussins de mousse épousant la forrne des deux premières intercarênes s'effectue par élagage au cuter aux mensurations de la tortue.

Lors du marquage. la balise et l'interface sent maintenues par pression au moment du sanglage.

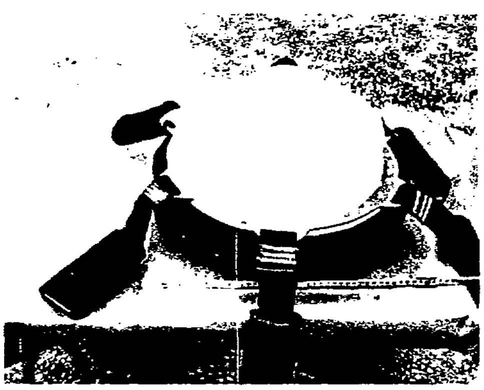


Photo M Duron

Les balises

Balise prototype : choisie parmi les balises type transat (CEIS). elle a été modifiée par le CNES Argos de la façon suivante :

- Utilisation de la mécanique et une partie de l'électronique de la bake Transat no 220.
- Installation d'un émetteur ayant déjà navigué (émetteur no 1 47).
- OUS sol ayant déjà navigué.
- Suppression des i nterrupteurs extemes et des opturateurs des orifices par vis écrou et joint, ce demier étant placé a l'extérieur de la balise.
- Potting de l'intérieur de la balise à l'aide de mousse syntactique Eccofdam EFF1 4 et Eccofdam MD27.
- Des arceaux métalliques ont été réalisés pour soutenir la coque en polycarbonate, en plus de la mousse syntactique pour assurer une étanchéité et une rigidité en immersion jusqu'à 150 m de profondeur (cf.: M. Leroy, CNES).

Le prototype actuel muni de l'électronique et de vingt piles au lithium nécessaires pour une durée de vie d'un cycle annuel, atteint un poids de 9,5 kg.

Balise factice: réalisée aux normes de la balise Argos prototype en bois plastifié et lestée pour atteindre un poids de 9,5 kg, elle est utilisée pour les essais de fiabilité du harnais.

Hamais balise interface

Le complexe harnais-balise-interface a été conçu de manière à ce que son poids de 12,5 kg s'annule totalement en immersion (Principe d'Archimède). Cet équilibre parfait est absolument indispensable puisque par définition, un excès de poids provoquerait la noyade de l'animal qui ne pourrait remonter à la surface, et inversement, une trop grande flottabilité empêcherait les plongées physiologiques de la tortue.

Pose du hamais

Après capture dune tortue Luth, soit en Guyane, sur la plage des Hattes, lors de la nidification, soit en France, clans les filets pélagiques de deux chalutiers des Pertuis Charentais, le déroulement de la pose du hamais se décompose comme suit:

1° Déposer les sangles à plat sur le tenain;
2° Amener la tortue choisie:
3° Déposer l'animal sur les sangles à plat;
4° Faire converger les sangles antérieures et postérieures autour de la carapace:
5° Pose de la balise munie de l'interface:
6° Bouclage des sangles;
7° Rivetage de sécurité des sangles;

Le temps estimé pour la réalisation de la pose du hamais et de la balise sur la tortue Luth est de 15 minutes.

Des ameliorations seraient a apporter clans le domaine de l'hydrodynamisme. Mais it doit cependant satisfaire aux contraintes précédemment évoquées. Un replacement des piles au lithium par un systeme à cellules photo voltaïques permettrait de prolonger l'expérience finale sur deux cycles annuels.

Les essais du hamais. avec balise factice et balise munie de l'électronique rentrent clans le cadre d'un programme Museum National d'Histoire Naturelle présenté au Groupe de Recherche et d'Etude en Océanographie Spatiale (G. R.E.O.S.).

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Harnesses for leatherback turtles

The Natural History Museum of La Rochelle (France) has been using the Argos system for many years to track leatherback turtles (Dermochelys coriacea) in the Atlantic. Particularity significant work has been done in designing a harness to strap the PTT to the turtle.

The project involves fitting specially adapted yacht-type P77s to fiue subjects in their French Guiana nesting zone, and three in the Charentais Straits (France). the summer feeding ground. Data are transmitted ouer a complete one-year cycle.

The aim is to determine whether true transatlantic migration takes place, or merely scattering of individuals by trans-oceanic currents (see Argos Users Conference Report April. 1982).

Notes: 1) Dermochelys coriacea differs from the other Cheloniidae by the absence of bong scales on the ridged dorsal shell, as well as by its size (length up to 2.40 m). and by its weight (betwcen 350 and 600 kg).
2) Radio-tracking using directional antennas was first carried out in the Charentais Straits in 1978 (M. Duron, 1978). The techniques used to fix the PTT to the animal (see Argos Newsletter Nº 11. 1981) led to the development of the harness presently under discussion

The harness

The harness is used to fix the PTT to the turtle's back. somewhat nearer the head than the tail. This permits transmission during phases when the animal partially emerges from the water to breathe or swallow.

Design objectives included:

- *ruggedness: the unit had to be capable of withstanding corrosion and hydrodynamic forces throughout a one-year cycle;*
- *simplicity: the dangerous conditions at Les Hattes beach (French Guiana) prohibited sophisticated handling procedures and dictated swift and simple attachment devices;*
- *speed: maximum handling time was fixed at 1 1/2 hour (total time out of water for nesting) so as to ensure minimum interference with the subject's normal behaviour:*
- *close fit of the pad between the PTT and the animal. to allow the*

animal aimed to behave normally, and minimal size so that cutaneous breathing would also be as normal as possible. In addition, injury to the subject was to be avoided.

These considerations eventually led to a design consisting of six 5-cm-wide webbed nylon straps, sewn together at the tress-over points (see diagram). These straps pass through slots in the stainless steel ring supporting the PTT, and then buckle back onto themselves. A rubber connector on each strap provides elasticity, needed both when fitting the harness and to give the animal freedom of movement throughout the year. The buckles are wrapped in neoprene foam to protect the shell from chafing. The straps cross each other at the plastron and fasten above the dorsal shell, converging on the PTT.

The harness can be used on any adult leatherback turtle.

The pad

The pad is used to ensure that the lower part of the PTT bears on a relatively flat surface, again without hindering normal behavior.

Composed of 12 superposed glued neoprene foam disks, measuring 42 cm in diameter and 8 cm in height, the pad is split to accommodate the lengthwise ridge of the dorsal shell. The lower disks are sculpted on the spot to allow for the shape of the two inter-ridge spaces.

During fitting of the straps, the PTT and pad are held firmly in place.

The PTT

1) The prototype was chosen from the various CEIS-Espace yacht-type PTTs, and modified by Service Argos. The mechanical assembly and part of the electronics were taken from Transat PTT N° 220. The transmitter electronics (PTT N°147) and the L/SO (ultra-stable oscillator) were also units that had already been in service.

External switches were dispensed with, and hole plugs were replaced bya screw-nut-and-seal. The inside of the PTT was filled with Eccofdam EFF14 and Eccofdam MD 27 synthetic foam. Metal ribs were fitted to reinforce the polycarbonate shell and synthetic foam, required to ensure water-tightness and rigidity during immersion down to 150 m (see Leroy, CNES). The present prototype, complete with electronics and 20 lithium batteries (lifetime: one year), weighs 9.5 kg.

2) The dummy model was made out of plastic-coated wood to the dimensions of the prototype, and weighted to gives a total mass of 9.5 kg. It was to be used in reliability tests on the harness.

Harness-PTT pad

The harness-PTT-pad unit was designed so that its total weight (12.5 kg) would be canceled out during immersion, due to buoyancy. This is of course essential, since too great a weight would drown the animal, while too little would prevent it from diving normally.

Fitting. the harness

Leatherback turtles are captured either on Les Hattes beach (French Guiana) during the nesting season, or in deep-sea trawler nets in the Charentais Straits.

The harness is fitted as follows:

1) the straps are laid flat on the ground;
2) the turtle is brought forward and placed on the straps;
3) the fore and rear straps are brought together around the turtle's shell;
4) the PTT and pad are then fitted;
5) the straps are buckled;
6) the straps are safety-riueted.

The total estimated time required to fit the harness and PTT is 15 minutes.

The system can be further improved, particularly as regards hydrodynamics, though the constraints mentioned aboue of course remain. Second[g, replacing lithium batteries by a system of solar cells would extend the life of the PTT, and thus that of the experiment, to two one-year cycles.

Harness trials, both with the dummy PTT and the unit complete with electronics, were performed as part of a Museum National d'Histoire Naturelle program presented to the Groupe de Recherche et d'Étude en Océanographie Spatiale (GREOS).

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SUIVI D'OISEAUX

Cest en 1981 que j'ai commencé mes recherches à la station sur le terrain de Culterty de l'Université d'Aberdeen (Prof. G. M. Dunnet, Dr 1. G. Priede). Ces recherches ont porté sur la conception d'une plate-forme micro-miniaturisée plus particulièrement destinée aux oiseaux. Si cette tithe a été entrepnse c'est parce que la liaison de télécommunication par satellite permet de surmonter au mieux les limitations de propagation du champ de vision liées aux systèmes de radiogoniométrie au sol actuellement utilisés pour le suivi des oiseaux clans leur -milieu nature].

Ce projet part de l'idée que les solutions techniques doivent à la fois permettre d'obtenir un ensemble électronique d'encombrement et de poids réduit pouvant être transporté par l'oiseau et perrnettre la resolution de bien des problèmes posés par d'autres études sur les animaux.

Plusieurs prototypes de plates-formes ont déjà été constructs. Les premiers équipements comprenaient des composants standards implantés sur des circuits imprimés deux fois grandeur nature pour faciliter le travail experimental. Les équipements qui viennent d'être réalisés ne pèsent plus que 78 g pour un diamètre de 98 mm, comme le montre la figure 1. Une réduction encore plus poussée est envisagée à l'aide des techniques par film épais.

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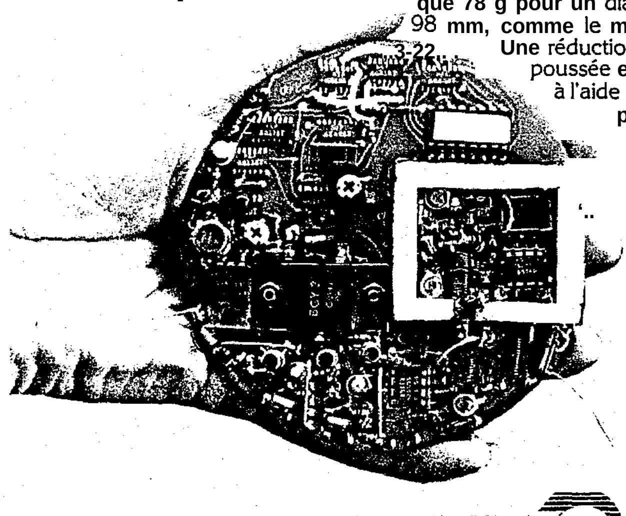


Biologie-biology

Afin d étudier expérimentalement l'aérodynamique des boitiers et le moyen le plus approprié de fixation, on a du procéder à des essais de montage de ces ensembles sur des oiseaux en captivité observés pendant des périodes de temps prolongées en 1982.

Le boitier de protection de l'ensemble électronique est en nickel pur. Son contour réalisé par électro-formage représente l'aboutissement d'essais minutieux en soufflerie (Figure 2).

Un gros effort a également été fourni en matière de conception d'antennes appropriées, l'accent étant mis plus particulièrement sur la façon dent la polarisation de puissance à partir de monopoles élevés (à 401.65 MHz) pouvait être réduite.

Plusieurs options en matière d'alimentation ont été examinées et j'ai constaté que bien peu de capteurs primaires ou secondaires fonctionnant soit de façon autonome ou relié à des capteurs solaires parvenaient à débiter 0.45A pendant 360 ms avec la planéité de tension exigée aux homes. L'alimentation constitue un handicap sérieux à une microminiaturisation encore plus poussée.

Un récepteur de champ a également été conçu. Il offre au biologist la possibilité de déterminer l'état opérationnel des plates-formes lors de leur déploiement. Ce récepteur permet également de localiser avec précision les plate-formes équipées d'une balise VHF en vue de leur récupération ultérieure. Des récepteurs et antennes ont aussi été fabriqués pour couvrir la frequence 136.77-137.77 MHz de la liaison descendant du satellite. le but étant de réaliser à l'avenir des travaux sur une station de réception directe de faible coût.

Une thèse sur ce sujet doit être publiée cet été et ma petite entreprise est censée fabriquer les plates-formes et les équipements correspondents.

John French
Mariner Radar Ltd

TRACKING BIRDS

In October 1981 I began research at the University of Aberdeen Culterty field station. (Prof G. M. Dunnet, Dr. I. G. Priede), with the object of designing a microminiature PTT specifically for birds. This was undertaken because the use of a satellite — based communication link provides the only effective wag of overcoming line — of — sight propagation limitations associated with earth — based direction finding systems currently used for tracking birds in the wild. The thinking behind the project was that engineering solutions to a package small and light enough for a bird to carry must also solve many of the problems associated with other animal studies.

Considerable work has also been done on de-signing suitable aerials with particular attention given to finding a means of reducing the size of the ground plane required when radiating power from elevated monopoles at 401.65 MHz.

Various options for power supply were examined and I found that few primary or secondary cells are capable of supplying 0,45A for 360 MS with the required terminal voltage flatness either as stand-alone power units or used in combination with solar cells. The power supply pesents serious limitations to further size reduction.

Several prototype PTTs have now been built. The first units used standard components on a printed circuit twice full size to make experimental work easier. Later units are reduced to 98 mm in diameter with a mass of 78 grams as shou wn in fig. 1. Further reductions in scale are planned using thick film techniques

Investigations into casing aerodynamics and a suitable means of attachment involved the fitting of trial packages to birds in captivity and under observation for extended periods in 1982. The electronic assembly is contained in a pure nickel housing electro-formed to a contour carefully derived by wind tunnel testing. fig. 2.

the operational status of PTTs during deployment This can also be used to precisely locate PTTs containing a W-IF beacon for recovery purposes. Receivers and aerials have also been produced for the satellite downlink frequency of 136.77-137.77 MHz with a view to future work on a low-cost Local User Terminal.

It is intended to publish a thesis on the subject this summer and for my own small company to produce the PTTs and associated equipment.

John French
Mariner Radar Ltd

Les émetteurs certifiés pour le suivi des animaux

Afin de pouvoir être suivis via Argos, les animaux doivent être équipés dun émetteur dent le modèle a été certifié par le Service Argos.

Ces émetteurs peuvent être constructs par n'importe quel constructeur, industriel ou organisme public.

Le but de la certification est de s'assurer que les émetteurs, fabriqués suivant un modèle type, sent compatibles avec l'instrument embarqué et ne perturbent pas la réception des autres plates-formes.

Pour obtenir la certification, le constructeur doit essentiellement envoyer un modèle type de son émetteur à Toulouse, pour y subir les essais de certification.

La certification obtenue est aussi valable pour tous les émetteurs techniquement identiques au modèle soumis aux essais.

En ce qui concerne les émetteurs certifiés destinés au suivi des animaux, plusieurs problèmes techniques spécifiques ont dû être résolus :

. l'alimentation électrique de l'émetteur : afin de prolonger le temps de fonctionnement des batteries il est recommandé :

sur les ani maux terrestres, d'utiliser des cellules solaires,

- sur les animaux marins, d'interrompre le fonctionnement de l'émetteur lorsque l'animal est en plongée (utilisation dun manocontact);

- la masse et l'encombrement de l'émetteur : doivent être compatibles avec la masse et le volume de l'animal ;
- les contraintes mécaniques : sur les animaux marins les émetteurs doivent être capables de résister aux fortes contraintes dues à l'environnement marin: pression, salinity . . .

Les principals caractéristiques des émetteurs certifiésw, destinés essentiellement au suivi des animaux, sent regroupées sur le tableau ci-joint. Les adresses des constructeurs sent indiquées clans la liste des constructeurs certifiés, publiée clans ce journal.

Le tableau ne regroupe que les émetteurs actuellement certifiés (i.e. au 1[er] mars 1983). De nouveaux matériels, en tours de développement, devraient être certifiés au tours des prochains mois: il s'agit notamment d'une électronique de Telonics (en tours de certification) et d'une électronique anglaise. Saris compter bien sûr, d'autres matériels pouvant être développés par des constructeurs non encore connus du Service Argos.

En conclusion à cette synthèse, il faut constater que cette application d'Argos a permis de réaliser des progrès techniques énormes sur les émetteurs et leur miniaturisation, progrès dent devraient certainement tirer profit à court terme tous les autres domaines d'application d'Argos (bouées dérivantes miniatures, etc.).

Constructeur *Manufacturer*	Type de l'émetteur *PTT model*	Plage de température *Temperature range* Mini	Maxi	Masse *Mass*	Date de certification *Date of certification*	Animaux *For use with*
Applied Physics Laboratory	BF4	+10"C	+45°C	150g	Octobre 1983 *October 1983*	Oiseaux *Birds*
Telonics	CM 10001-002	- 20°C	+ 40"C	450 g	en tours *in progress*	Animaux terrestres *Land animals*
Toyo Corn,	T 2014	- 5°C	+ 50"C	500 g	Janvier 1983 *January 1983*	Animaux marins *Marine animals*
Wood-hey	165	– 20°C	+ 55°C	800 g	Mai 1982 *May 1982*	Animaux marins *Marine animals*

Certified PTTs for animal tracking

As in all applications of the Argos system, PTTs for use in animal tracking must be of an a'p roved model, that is, they must haue been certified by Seruice Argos. The user is, of course, free to deal with the manufacturer or organization of his choice.

The aim of the procedure is to ensure compatibility between PTT's and the satellite onboard equipment, and also non-interference with other Pros.

To apply for PTT certification, the manufacturer sends a model to Service Argos (Toulouse) for certification testing. Certified designs are then considered valid for all identical units.

The design of PTTs specifically for use in animal tracking poses certain problems, for example:
- *PTT power supply: to ensure maximum battery life, the use of solar ceils is recommended for land animal tracking, and switches that turn the PTT off when the subject is diving for marine animal tracking;*
- *the mass and volume of the PTT must be compatible with the nature of the animal;*
- *mechanical forces are frequently severe, in particular in the case of marine animals; PTTs must be capable of withstanding such phenomena as pressure and salinity and other features of the marine environment.*

The main characteristics of a number of certified PTTs used in animal tracking are given in the table. The list on page 15 of this Newsletter gives the addresses of the manufacturers.

The table shows only presently certified PTTs (as of March 1, 1984). New hardware is currently being develoned. and should be certified during the coming months, for example a new, lighter PTT which is on its way from the American company Telonics, and another from a British manufacturer. There may, of course, be others "in the pipeline" of which Seruice Argos is not yet aware.

Work on animal tracking via the Argos system has enabled great strides to be made in PTT design, in particular as far as size reduction is concerned, and the progress made is certain to benefit other applications.

NOUVELLES CERTIFICATIONS

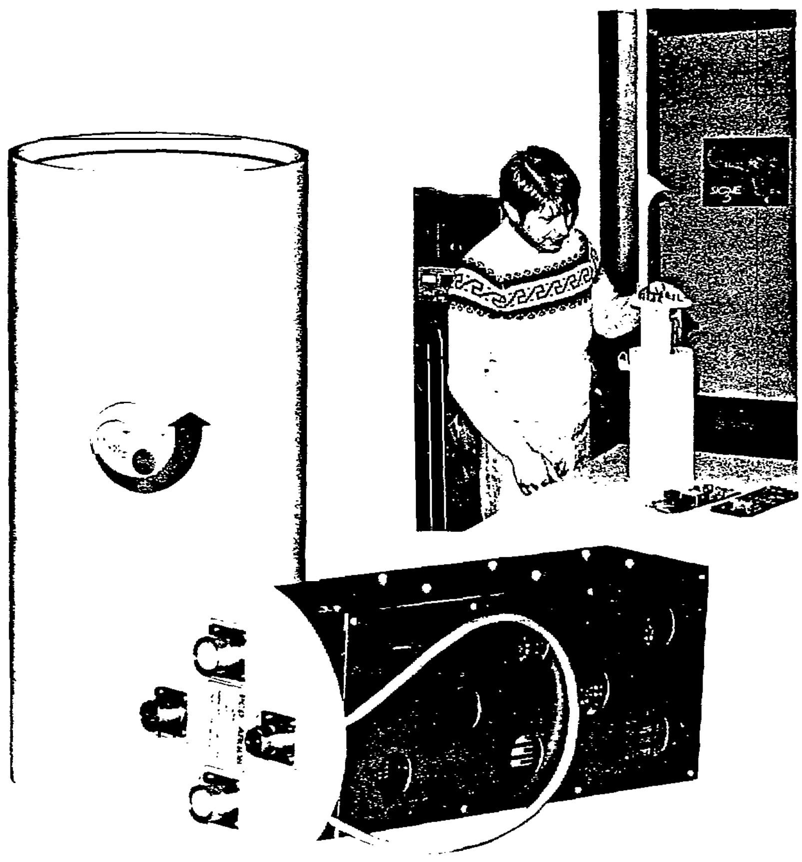
4 novembre 1983
Certification dun émetteur type UHF 83 de CEIS Espace piloté par microprocesseur, localisable de — 20 à + 50°C et d'un poids de 500 g. Cet émetteur, alimenté en 12 V, a une puissance de sortie de 33 dbm et se présente clans un cylindre de 0 130 X 90 mm. Du fait **de sa forrne** il est particulièrement adapté **pour** équiper les bouées dérivantes.

21 novembre 1983
Certification **dun** émetteur . série **A.** de l'INPE (Instituto de Pesquisas **Espaciais)** du Brésil destiné à des expériences d'hydrologie. L'émetteur **est clans** un boitier **de protection** cylindrique **en PVC** rigide.
Dimensions, 0165 X 370 mm
Poids :3,25 kg
Bien que prévue **pour etre** utilisée **en** collecte **de** données cette plate-forme **est** localisable **clans une gamme de** température **de** - 20"C a +50°C.

PTT's THE LATEST CROP

November 4, 1983
Saw *the* **certification** *of* **the** *CEIS-Espace microprocessor.controlled UHF 83 location-type PTT. The new model (12 V) weighs 500 g and operates at temperatures between — 20 and + 50°C. Its* **output is** 33 *dBm. and dimensions 130 mm in* **diameter** *by* **90** *mm Its cylindrical shape makes it particularly suitable for* **use on** *drifting buoys.*

Just **17 *days* later**
Another new PTT **was** *certified by Service Argos, this time a model* **produced by the** *INPE (Instituto* **de** *Pesquisas Espaciais) of Brazil. This "series* **A**" *model is for use in hydrologic experiments and comes in a protective cylindrical PVC package. Measuring 165 mm in diameter by 370 mm, it weighs in at* **3.25** *kg. Although primarily intended for data collection,* **the** *PTT can be located at operating temperatures between – 20 and + 50°C.*



Distribution du film Argos 2

Suite à de nornbreuses demandes de la part de lecteurs concemant **la** possibilité **de se procurer** une copie **du** récent **film de promotion** Argos 2 • (durée : **22 minutes.** langue : anglais ou français, à spécifier), le **Service Argos** a le Plaisir d'annoncer **que:**
• le réalisateur **du film, la** Société CERES-FILMS, **assure directement la distribution de copies sous** les **formats** suivants (tarif valable jusqu'au **31.12.&):**
- **Film 16 mm, au prix unitaire de 2200F:**
- Video U-MATIC, **standard PAL** ou SECAM, **au prix de** 850 **F**
- **Video** VHS, **standard PAL** ou SECAM, **au prix de 600 F.**
Pour commander une de ces **copies** il **faut** adresser **directement la commande (en** spécifiant **la** langue, le **format et** éventuellement **le standard** TV) et le paiement **au** réalisateur, à l'adresse suivante :
CERES-FILMS
8O. rue de Saussure
75017 Paris — France
• **des copies video** NTSC seront bientôt disponibles **en** s'adressant **au bureau USA du** Service **Argos:** les modalités **de commande et** les **prix seront** publiés **clans** un prochain numéro de l'Argos Newsletter.

The new Argos film

Many readers have expressed interest in obtaining copies of the film "Argos 2". now available in either English or French. Service Argos **has pleasure** *in* announcing *that the film. lasting* **22** *minutes, can be obtained directly from the producers. Céres Films. The 1984 unit prices* **of the** *various versions* ***are as follows:***
• *16-mm film: FF* **2200:**
• *U-MATIC Video* ***(PAL or SECAM) : FF 850:***
• *VHS Video (PAL or SECAM): FF* **600.**
Orders, *specifying the language and video and TV standards required. should be sent* **together** *with payment to;*
CERES FILMS
80, rue de Saussure.
75017 Paris — France
NTSC versions of the film will soon be available from Service Argos' United States office: prices and ordering procedure will be published in a forthcoming issue of the Newsletter.

CERTIFICATION

Liste des **constructeurs fabriquant** des terrrrinaux de **transmission certifiés** par **le** Service Argos.

The following firms are currently manufacturing Platform Transmitter Terminals (PTTs) that have been certified by Service Argos.

Bristol Aerospace Limited
P.O. BOX 874
Winnipeg Manitoba
Canada
Mr. F. Berard
Tel. (204) 775.83.31
Telex 0757774

Ceis **Espace**
Zone Industrielle de Thibault
31084 Toulouse Cedex
France
Mr. B. Fromantin
Tel. (61) 44.39.31
Telex 521039

Eidsvoll Electronics
P.O. Box 38 N. 2081
Eidsvoll
Norway
Mr. L Nordby
Tel. (6) 96.42.30
Telex 72091

Hermes Electronics Limited
40 Atlantic Street
P.O. Box 1005, Dartmouth
Nova Scotia B2Y 4A1
Canada
Mr. R. Walker
Tel. (902) 466.74.91
Telex 01921744

Instituto de Pesquisas Espacias
C.P. 515
12200 Sao Jose dos Campos-SP
Brazil
Mr. N.J. Panrda
Tel. (123) 22.99.77
Telex 1121534

Johns **Hopkins** University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, Maryland 20707
U.S.A.
Mr. T. Strikwerda
Tel. (301) 953.71.00
Telex 89548

National **Center for Atmospheric Research**
P.O. Sox 3000
Boulder, CO 80303
U.S.A.
Mr. C. Morel
Tel. (303) 494.51.51
Telex 0450213

Polar **Research** Laboratory Inc.
Santa Barbara Street 123
Santa Barbara, CA 93101
U.S.A.
Mr. W.P. Brown
Tel. (805) 963.19.29
Telex 9103343465

Toyo Communication Equipment Co Ltd
N.8. Mori Bldg -
20.4 Nishi Shimbashi
Tokvo 105
Japan
Mr. M. Tsutsumi
Tel. (03) 436.21.80
Telex 02423115

Wood lvey **System** Corporation
3535 Forsyth Road
Orlando, FL 32807
U.S.A.
Mr. G.S. Smith
Tél. (305) 678.61.16

Vente des textes des conférences utilisateurs

(Le prix de vente permet de couvrir les frais d'impression, de traduction et d'envoi)

Les textes peuvent être commandés au Service Argos en nous adressant ce bon de commande.

Bon de commande

Valable jusqu'au 31 décembre 1984
A renvoyer avec paiement à :
Service Argos
18, avenue Édouard-Belin
31055 Toulouse Cedex
France

Documentation à envoyer à :
Nom
Organisation
Adresse

demande que **Service Argos 18, avenue Édouard-Belin 31055 Toulouse Cedex France** fournisse les documents suivants :

Conférence Argos Textes		Nombre d'exemplaires
1. San Francisco	28-29 oct. 1981	
2. Paris	20-22 avril 1982	
3. Annapolis	13-15 déc. 1982	
4. Londres	27-28 sept. 1983	

Prix unitaire en francs français

Hors Europe	Europe hors France	France T.T.C.
250	200	214

Lors de la commande, *les paiements doivent être rédigés* à l'ordre de l'Agence Comptable du CNES.

Date
Signature et cachet

ARGOS
CLS SewIce Argos 18, avenue Edouard Belin 31055 Toulouse Cedex France. Tél 61274351 Télex 531752 F
Service Argos Inc. Inglewood office Canter II annex 1801 MC Cormick Drive Landover. Maryland 207S5 USA
CLS COLLECTE LOCALISATION SATELLITES
NEWSLETTER
JUIN/JUNE 1986 N° 26

REPLACEMENTS DES CARIBOUS
DANS L'ARCTIQUE OCCIDENTAL

MOVEMENTS OF CARIBOU
IN THE WESTERN ARCTIC HERD

SPECIAL
SUIVI D'ANIMAUX

Au tours du printemps 1984, les chercheurs du Wildlife-Wildlands Institute ont entrepris une étude des replacements et des migrations d'un troupeau de caribous de l'Arctique occidental au moyen des satellites ARGOS-TIROS. Ce troupeau est le plus grand d'Alaska et il occupe la zone nerd-ouest de l'état, qui est la plus reculée du pays. De récentes estimations évaluent sa population à 180000 têtes environ.

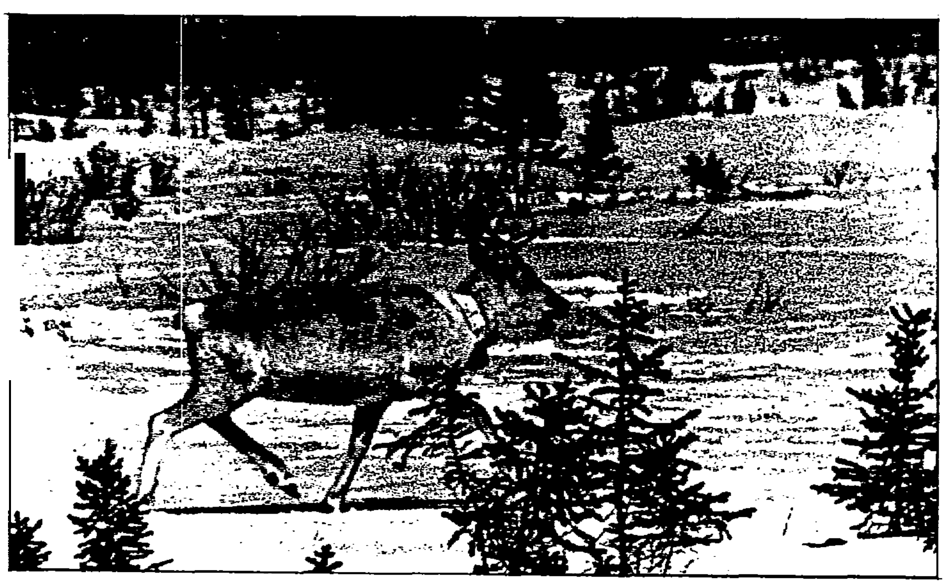
En mai dernier, deux femelles ont été capturées pres de Selawik en Alaska. Un collier renfermant 1a plate-forme émettrice certifiée par le Service Argos et développée par Telonics Inc. (Mesa, Arizona), a été placé sur les deux femelles qui ont ensuite été relachées. Pour preserver la durée de vie des batteries, les plates-formes devaient transmettre un jour sur trois. Chaque collier renfermait également un émetteur UHF, ce qui a permis aux chercheurs de localiser et finalement de récupérer par avion un des colliers. En raison de la nature grégaire du caribou, les replacements de ces deux femelles étaient représentatifs des déplacements de l'ensemble de la population femelle du troupeau.

SPECIAL
ANIMAL TRACKING

In the spring of 1984, scientists from the Wildlife-Wildlands Institute began tracking the movements and migration of caribou in the Western arctic herd via the ARGOS-TIROS satellites. This herd is the largest in Alaska and inhabits the remote northwest corner of the state Recent estimates place its size at about 180,000 animals.

In late May, two female caribou were captured near Selawik, Alaska. Each was fitted with a prototype, Argos-eertified PTT collar developed by Telonics Inc. (Mesa, Arizona) and released. To conserve battery life, the PTTs were programmed to transmit signals every third day. Each collar also contained a UHF transmitter, which enabled scientists to locate and eventually retrieve one of the collars using fixed-wing aircraft. Due to the gregarious nature of caribou, the movements of these two females were indicative of the general movements of the female segment of the herd.

After release, the caribou travelled north over the Brooks Range to traditional calving grounds where, in June, they each gave birth to a healthy calf. They then moved west to the shore of the Arctic Ocean where the bulls began to join the herd. Throughout the brief arctic summer, the caribou moved east along the foothills north of the Brooks Range. Then in September, they begart heading south. One of the cows was killed by a grizzly bear near the Noatak River in early September; the PTT was subsequently recovered.



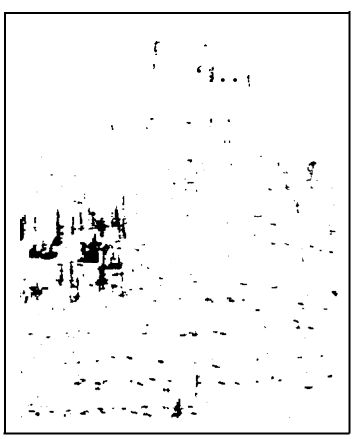
SPECIAL ANIMAL TRACKING

The other cow continued south with the herd to the Selawik Hills where she wintered. Battery failure occurred for both PTTs at the end of September after about four months of operation. Each animal was tracked over 1500 miles at a rate of about 10 miles per day. The UHF transmitter permitted researchers to locate the other cow throughout the winter.

Based on the success of the first year, two additional females were instrumented with PTTs last June, after they had reached their calving grounds north of the Brooks Range. One cow already had a calf; the othe gave birth one week after capture. The movements of these females were similar to the previous year. In the summer, however, one of the females moved several hundred kilometers further east than either did the previous year, crossing the Anaktuvuk River; then in the late fall, both females travelled about 100km further south, reaching the Unalakleet drainage in the Nulato Hills.

The Telonics PTTs have performed extremely well under the adverse arctic conditions. Each year battery life has been extended, and overall performance improved. As of this writing, one of last year's PTT's is still transmitting daily locations. The Wildlife-Wildlands Institute plans to deploy six more PTTs this spring. Four will be placed on caribou and two on grizzly bears.

Derek Craighead
Wildlife-Wildlands Institute
5200 Upper Miller Creek Road
Missoula, Momma 59803
(406) 215-3867



AN ARGOS-MONITORED RADIO TAG FOR TRACKING MANATEES

SPECIAL ANIMAL TRACKING

background

Field applications of satellite-monitored radio tags to marine mammals have had short-term success during experiments with humpback whales (Mate et al, 1983) andgray whales (Mate et af, 1984) This paper describes a totally new tag designfor an Argos PTT and its performance during its first field trial on a west indian manatee (Trichechus manatus) along the west coast of Florida.

The manatee is an endangered mammal and a fully aquatic herbivore. These animals typically swim slowly in shallow waters and feed almost continuously on freshwater and marine plants. In the summer, manatees are found as far north as North Carolina, but during winter their range extends north only as far as Florida. These seasonal changes in distribution reflect the manatee's intolerance of cold water. Most of the detailed information available on the movements of individual manatees has been collected with short-range VHF radio tags during the winter, when some manatees go up a few rivers having warm springs. There is little information available on the movements of manatees from March to November, because the animals, move into saltwater, where the short range of VHF radios precludes tracking. Such information is important for an understanding of manatee home range, foraging strategies, and energetic.

methods

On 5 February 1985, a captive adult male manatee, named "Beau", was fitted with a Telonics Platform Terminal Transmitter (PTT) in a specially designed housing. Beau had been in captivity since January 1979, when he was found in Gulfport, Mississippi suffering from cold stress. He was originally rehabilitated at Sea World of Florida and then moved toHomosassa Springs Attractions. Prior to its tagging, the manatee was moved to the Homosassa Spring itself, which is the source of a tributary running into the Homosassa River, The tagged manatee was limited to a 500 m diameter area for two weeks by a wire fence crossing the tributary. During this impoundment, we evaluated the accuracy of PTT locations, the performance of the attachment and the manatee's behavior. The manatee was released into the Homosassa River 14 days after tagging (19 February). The release was made two weeks before offshore water temperatures were expected to be warm enough for manatees to tolerate so the released manatee might "learn" that rivers were warm water refuges. Fifty days after its attachment, the PTT-equipped manatee was located with a Telonics TR-2 Argos uplink receiver and the PTT was removed.

The U.S. Fish and Wildlife Service developed an attachment system for VHF tags (Rathburn, in prep.), which was also used for the PTT. A strap around the caudal peduncle of the manatee secured a 2 m flexible nylon rod by a swivel. At its other end, the nylon rod was attached to the floating PTT through another swivel. The Telonics-built PTT was housed in a PVC tube 35 cm long and 4.5 cm in diameter. Both PVC end caps were made water-tight by O-ring seals, One end cap was a 4.5 cm long cone designed to shed weeds which attached to the nylon rod through a swivel at its tip. The other end cap was flat with a stainless steel insert to act as a ground plane and base for a 12 cm external whip antenna. The positively buoyant PTT floated *vertically with* the antenna and 3-4cm of the housing above water when the manatee was not swimming.

The PTT transmitted once every minute and sent activity and PTT temperature data encoded as 32 bits following the PTT identifier. The activity data related to mercury switch closures when the PTT tipped more than 90 degrees. Transmissions included summaries of the number of times the mercury switch closed in the preceding 30 minute period and during the previous 6 hour period. Internal temperatures of the PTT were measured to the nearest 0.03 degree C. Service Argos calculated locations when enough messages were available. Locations were calculated on the basis of 3 different *Service* Argos criteria. Location and sensor data were recovered from ServiceArgos in three ways. 1) U.S. Fish and Wildlife personnel collected telex files at least once each day using a Radio Shack Model 100 portable computer to interrogate the Argos computer files through Tymnet and Transpac;
2) OSU personnel collected dispose files

truthing will be quite difficult. We recommend that Service Argos attempt to provide a spectrum of user services with more flexible software options when they next have an opportunity to redesign their systems. Examples of useful user options would include:

1) location determinations from as few as three messages, even with reduced accuracy;

2) direct access to full data sets in archives and

3) retention of dispose/telex files for longer periods.

This paper is only a preliminary report of an experiment which is still in progress. Fifty days after the initial tagging, the manatee was relocated and the PTT removed. New batteries were installed and the PTT was reattached to the same animal. As of 20 May the PTT was stiff attached and performing well. As ocean temperatures warm, the PTT-equipped manatee may start ranging farther from the river systems to use the nearshore waters of the Gulf of Mexico. This will be exciting, as virtually nothing is known of manatee ocean movements.

acknowledgements

We are indebted to Vin Lally, National Center for Atmospheric Research (Boulder, Colo.) for his help in initiating marine mammal tracking with PTT's, his sustained interest and continued support; to Dave Beaty, Stan Tomkiewicz, and Boyd Hansen, Telonics, for their generous *contributions of time and equipment; and to the Homosassa Attractions for their cooperation.*

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U.S. Fish and Wildlife Service
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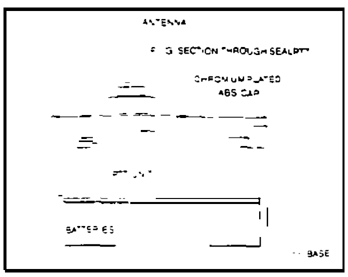
Ca. 934520067

James Reed
U.S. Fish and Wildlife Service
412NE 16th Ave., Gainesville
FL 32601

ENVIRONMENTAL HOUSINGS FOR ANIMAL PTT'S

SPECIAL ANIMAL TRACKING

The design of a rang of animal compatibl housings is something of a challenge At one environmental extreme, migratory birds may attain an altitude perhaps 3000 metres where pressure and temperature are much reduced. At ground level, land mammals can weigh more than a ton and seem to spend long periods scratching or



ubbing themselves on trees and even ι strong housing will have limited ife. At another extreme sea mammals nay dive to > 1000 metres where the pressure on the housing reaches 10 MPa or about 100 atmospheres. In all cases it is necessary to design an antenna, unobtrusive to the animal, so that high DC to RF conversion efficiency minimises the size of the battery pack.

frequency stability

With all Doppler location systems accuracy is critically dependent on the transmitter frequency and the housing can play a crucial role in achieving the precision required (1 part in 10^9 over 20 minutes) to allow location. The problem can be brought under control minimizing thermal gradients as it is usually the rate of change of temperature that limits the ultimate stability of a quartz resonator.

eals

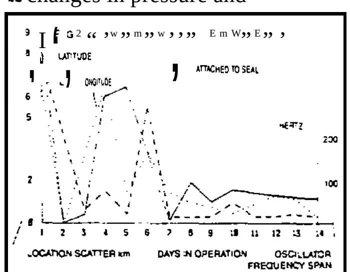
ig. 1 shows the main elements of a ?TT designed for seals. The housing s fabricated from AILS and can vithstand dives in excess of 00 metres (1000 kPa or about en atmospheres). The antenna is abricated from stainless steel wire tiffened with PVC sleeving, a ground lane is formed by chromium plating he exterior surface of the plastic. ncluding the batteries, the total veight is about 650 grams (see ref. 6). t is attached by a strong cotton mesh aced to the base of the PTT housing and embedded in the fur with epoxy esin. By timing the experiment elative to the annual moulting period the time it has to be carried by he animal can be minimised. [nspection of tagged animals after moulting shows no sign of the attachment. Fig. 2 shows how body heat stabilises the oscillator (data source NERC/SMRU experiment).

whales

Whale tracking PTT's can be housed in a glass bathymetric sphere (see Fig. 3). This protects the PTT from the considerable changes in pressure as he whale sounds or surfaces and the temperature span cart be limited to he main thermocline (4 to 20 deg. C) f measures are taken to reduce the effects of solar radiation. To minimise the chance of leakage the antenna is designed to radiate through the glass thus obviating penetrations.

birds

Birds present wide ranging problems as changes in pressure and

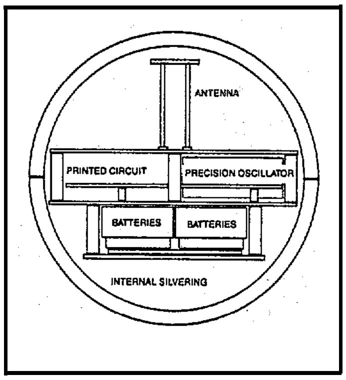


temperature both act upon the oscillator due to the very light weight housing required.
Significant location errors cart occur due to unknown altitude The errors introduced are almost entirely in longitude and increase by the tangent of the satellite elevation (see Fig. 5). To resolve this it is necessary for the PTT to carry an altimeter so that height data can be added to the

10 **atmosphères). L'antenne** est en **fil** d'acier **inoxydable rigidifié** par un manchon en PVC, 1a masse **étant** constitute par du chrome **recouvrant** la surface **externe** du **plastique.** Le **poids** total, **batterie comprise,** est de 650 **grammes** environ **(voir Réf.** 6).,. **L'ensemble** est **fixé** par un filet de **coton résistant, attaché** au **niveau** de la base du **boîtier** et **collé** clans la **fourrure** de **l'animal** par de 1a **résine** epoxy. En **synchronisant l'expérience** avec **les périodes** de mue des **animaux,** on peut **réduire le temps** pendant **lequel l'animal** doit porter **l'appareillage. L'inspection** des **animaux ainsi équipés après qu'ils aient perdu leur poil** a **révélé** la **disparition complète** de **toute fixation.** La Fig. 2 **montre** comment la **chaleur** du corps stabilise **l'oscillateur (source:** experience **NERC/SMRU).**

les baleines

Les plates-formes de **suivi** de **baleines** peuvent se **loger** clans une **sphère bathymétrique** en **verre (voir** Fig. .3). **Elle protège la plate-forme** des changements **considérables** de pression qui ont lieu **lorsque** la **baleine plonge ou** remonte **à** la **surface,** et la temperature **peut être limitée au thermocline** principal (4 **à** 20 **degrés** C.) **si** on **s'est efforcé** de **réduire les effets du rayonnement solaire.** Pour minimiser **les risques** de **fuite,** l'antenne est **conçue** pour



émettre au **travers du verre** qui **empêche toute pénétration.**

les oiseaux

Les oiseaux présentent toute une sé de **problèmes** du fait que **les changements** de **pression** et de temperature **agissent** sur **l'oscillateu** ceci **parce** que **le boîtier** doit rester tres **léger.**
Des **erreurs significatives** de localisation surviennent en **raison** d manque d'information **concernant l'altitude. Les erreurs observées** concernment **presque toujours** la longitude et augmentent **à** cause de **tangente** de **l'élévation** du satellite (Fig. 5), Pour **résoudre ce problème,** est **nécessaire** que la **plate-forme** so quipée d'un **altimètre,** de **sorte** que :s **données d'altitude** puissent **être** ıtégrées au message et **introduites** ans **les calculs** de localisation. Plus implement, **il** est possible de électionner **les localisations** a **partir** e passages **à basse** altitude **si** l'on onvient de **tolérer** une **certaine** nprécision.

a figure 4 **représente** une **plate-forme** e **taille suffisamment réduite** pour ouvoir **être équipée** sur **un oiseau** 'un **poids inférieur à** 8 kg. La atterie est **l'obstacle majeur** qui se ose pour **obtenir** une **réduction** plus nportante encore de **l'ensemble.** La onsommation moyenne est **d'environ** 0 mW bien que la **batterie puisse** mmir des **impulsions** de **0,5A avec ne interruption de 5% pendant 60** ms. **Lorsque l'on** utilise les **atteries primaires actuelles** comme ource **d'énergie, le** volume minimum st **aujourd'hui** de **300 ml** environ our **un poids** de 200 g. On va ìrement **bénéficier à** court terme 'améliorations, **grâce à un contrôle** [us **précis** des **périodes actives** pour :duire la consummation, et en ırveillant **les données** hysiologiques par **le système,** ce qui ıtorisera **des** reductions importances e la **taille** de **l'ensemble.**

eut-être que **le dernier** des **défis** uquel nous **avons à** faire **face, à** ıoins que **quelqu'un d'autre** ne soit lus **informé à** ce **sujet,** est la **plate-** ɔrme pour **poissons** qui est ctuellement **développée** (Fig. 6),

lle est **étudiée** pour se **libérer** ɔontanément et se **«désintégrer»** près une **période** de temps rédéterminée **(Réf.** 7).

John French
Université d'Aberdeen
et Mariner Radar Ltd ■

■ 1. Craighead, **F.C.** Jr.; Craighead, J. J.; **Cote,** C.E.; Buechner, H.K.; Satellite and ground radio tracking of elk. Animal Orientation and Navigation, NASA report SP 262. **1972.**

■ **2. Argos** users guide.

❑ 3. French, J. Tracking birds and sea mammals by **satellite,** Ph.D. thesis, University of Aberdeen, 1986.

❑ 4. **Priede,** L G.; A basking shark *(Cetorrhinus maximus)* tracked by satellite together with simultaneous

BALISE ARGOS BA15 POUR SUIVI D'ANIMAUX MARINS

SPECIAL SUIVI D'ANIMAUX

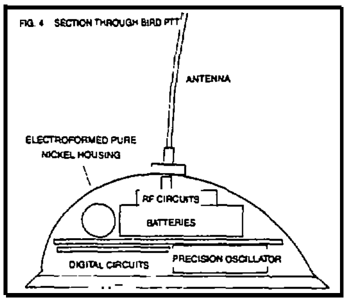
La **balise** ARGOS **BA 15 a été développée** par CEIS **ESPACE, plus particulièrement** pour **le suivi d'animaux marins** de forte **taille (baleines, tortues,** dauphins, **éléphants** de **mer...)** pouvant descendre **jusqu'à** des **profondeurs** de **plusieurs centaines** de **mètres.**
La localisation par le système ARGOS **s'effectue évidemment lorsque l'animal** est en surface.
La **balise** est constitute d'un **flotteur** hyperbarique compose de deux **hémisphères rodés à l'équateur** d'un **diamètre** de 10 **pouces protégés** par un **carénage** en ABS **thermoformé** de **couleur** orange.
Le flotteur contient l'émetteur ARGOS UHF 83, **l'antenne** et une **alimentation** par piles lithium (autonomic de 4 mois pouvant **être étendue à** un an en ne **faisant fonctionner l'émetteur** que huit heu sur **vingt-quatre) (voir schéma). L'ensemble** est **totalement étanche** e **garanti** en immersion **jusqu'à** 6000 **mètres** de **profondeur.**

La fixation de la **balise** sur **l'animal s'effectue** par **l'intermédiaire** de 4 **trous** aux 4 angles du **carénage.** 11 **appartient** aux **utilisateurs** de **définir eux-mêmes, le moyen le** mie **adapté** pour cette fixation, qui **dépend** essentiellement de l'animal **suivre** (singles,...).

B. Fromantin CEIS Espace ■

uplink signal and introduced into th cation calculation. More simply, it possible to select locations from low altitude overpasses if some loss accuracy is acceptable.

The outline of a PTT small enough be carried by birds with body eight > 8 kg is shown in Fig. 4. attery power density represents the ggest obstacle to further size reduction. The mean consumption i about 40mW although the battery must be able to supply 0.5A current ulses with 5% flatness for 360ms. When state of the art primary batteries are used as the power sour



the *present* minimum volume is abo 10 ml with a mass of about 200 grams. Short term advances are ore likely to be made by careful control of active periods to minimis power consumption and by onitoring physiological data through the system and than by substantial reductions in size.

Perhaps the ultimate challenge (unless someone knows better) is the Fish PTT currently being designed (see Fig. 6). This is intended to releas itself and "pop up" after a predetermined time (see Ref. 7).

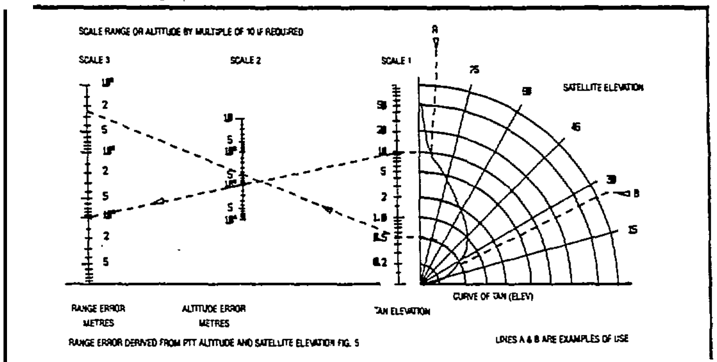
John French
University of Aberdeen,
and Mariner Radar Ltd.

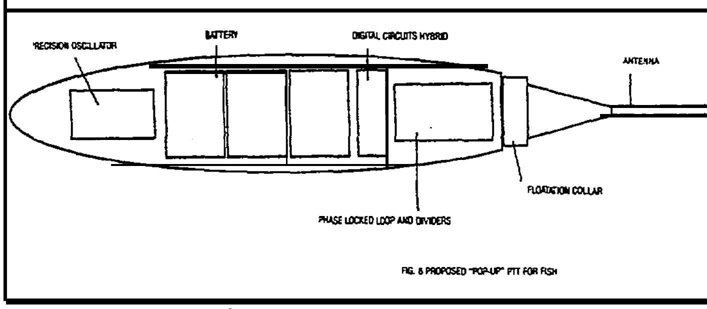
remote sensing. Fisheries research, N° 22, Nov. 1983.

■ 5. Oyharcabal, M.; Studies into location accuracy, Proc. Argos users Conf. London Sept 1983.

■ 6. Fedak, M.A.; Anderson, S.A.; Curry, M.G.; NERC Sea Mammal Research Unit, c/o British Antarctic Survey, High Cross, Madingley Road, Cambridge, Attachment of radio tags to the fur of seals. Mammal Society Notes No 46.

■ 7. NOAA Report on Dynamics of Tuna movement (1985).





BA 15 ARGOS PTT FOR MARINE ANIMAL TRACKING

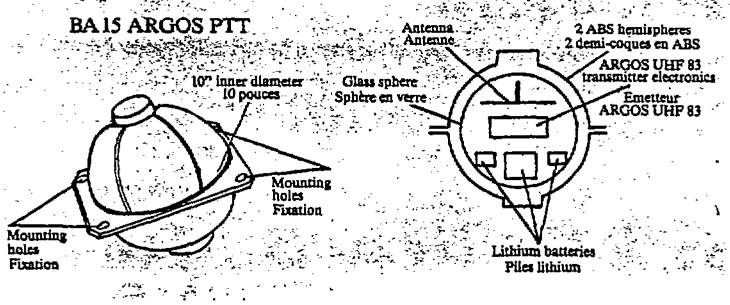
SPECIAL ANIMAL TRACKING

The BA 15 ARGOS PTT is designed by CEIS-ESPACE to track large marine animals such as whale, turtle, dolphin and elephant seal, species that dive to several hundred meters. Location is possible whenever the animal is at the surface.

formed ABS shielding (see diagram). The float contains the ARGOS UHF 83 transmitter electronics, antenna, and lithium batteries. The four-month operating lifetime can be extended to one year, providing the PTT is set to transmit 8 hours out of every 24.

The unit is fully watertight and is guaranteed down to 6000 m. FOUr

BA 15 ARGOS PTT

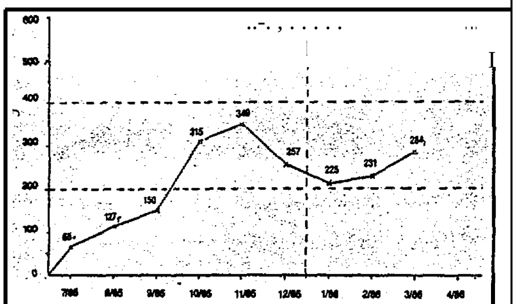


The PTT is packaged in a hyperbaric float comprising two 10-inch-diam hemispheres firmly mated along the great circle of intersection, and is protected by art orange-colored heat- mounting holes at the corners of the shielding help secure the PTT to the animal, the user deciding how best to fit the PTT (e.g. how to strap it on) according to theme of animal.

B. Fromantin CEIS Espace ■

QUELQUES CHIFFRES SUR INSTALLATION DE LA DISTRIBUTION

Depuis la mise en service de la ' **nouvelle** distribution nous **suivons** de **près l'évolution de son** utilisation. **Ainsi** pendant **le deuxième** semestre 85 nous **avons enregistré** plus de 20 **mille**



Nombre total **d'heures d'utilisation** par **mois.**
Total elapsed time per month

sessions **utilisateur avec** une moyenne **journalière d'environ** 125.
Pour **le** premier **trimestre** 86 nous **sommes déjà à** plus **de** 15 mine sessions **avec** une **moyenne journalière d'environ** 175 et **un** total de plus de **740 heures d'utilisation.**
Le nombre de sessions par jour (en moyenne) varie entre 100 et 250.

e jour **le** plus **chargé** de **la semaine** st **le** mardi avec plus de 320 sessions,

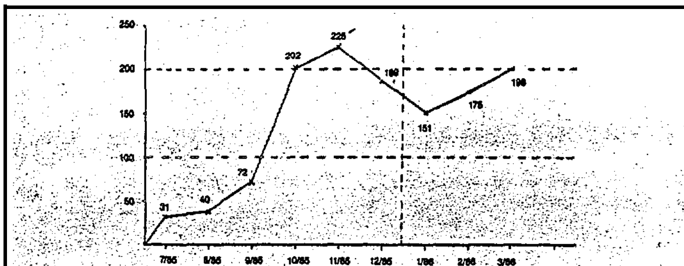
ıuant aux **heures, le nombre varie** n moyenne) **entre** 3 et 15 sessions.

es **heures les** plus **chargées** sent **à** 8 **heures** TU pour **le matin** et 2 **à** 15 **heures** TU pour **l'après-midi.**

i **l'on** compare ces **chiffres** avec **les** :atistiques **établies** pour 81 et 83, **il** 'y **a** pas **beaucoup** de **changement** oncernant **les jours** et **heures les** plus barges. Par **contre, il y a un grand** hangement concernant les ommandes **utilisées.**

Jusqu'à la mise en service de 1a **nouvelle** distribution 80070 des interrogations **étaient** sur **le fichier AJOUR** par **la commande COM. Depuis on constate** que **le** COM **n'est utilisé** que pour 45070 des interrogations **alors** que **le** PRV **représente** 55 **%** **maintenant.**
En **conséquence, il** nous **semble que** la mise en place de cent **heures** de **fichiers** TX pour tout **le monde** et **la** lecture non destructive de ces **fichiers** est **d'une grande utilité** aux **utilisateurs.**
Pour **conclure** sur ce **sujet, il** nous **semble opportun d'annoncer** que **les nouveaux** centres de **traitement auront** une **banque** de **données** en **ligne d'une capacité** de 15 **jours** (**fichier** DS) pour tous **les utilisateurs** en service STANDARD. Bien **sûr, les fichiers AJOUR** et TX **existeront également.**

Thomas A. Babits
Service Argos



Nombre moyen de sessions journalières par mois
Mean amount of daily sessions by month

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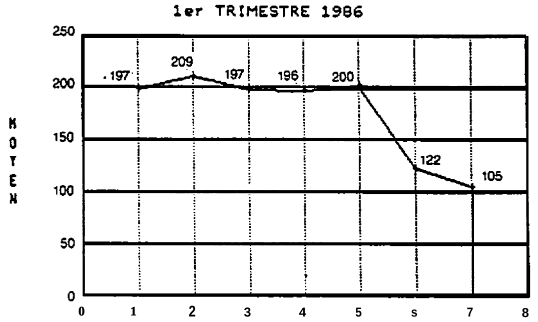
A FEW FIGURES ON THE NEW DISTRIBUTION SYSTEM

As you can **imagine, we have carefully** monitored use of the new distribution system since it was installed last year. During the second half of 1985, we recorded ***over , 20,000 user*** sessions ***(or dialogs), with a*** mean daily total of around 125. **For** the **first** quarter of 1986, we have sdready logged over 15,000 sessions, with a mean daily total of around 175 and overall logged-on time of **740 hours.** The number of daily sessions is usually between 100 and 250. The busiest day of the week is **Tuesday,** with more than 320 sessions. The number of sessions per hour varies from 3 to 15. The busiest periods in the morning **are** 7.00 to 8.00 **UTC** and in the afternoon 12.00 to 15.00 UTC. These "time" figures are similar to those recorded in 1981 and 1983, but there have been great **changes** in the commands **used.**

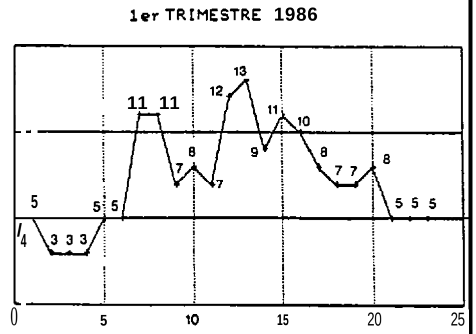
Under the old **system, 80%** of interrogations concerned the **AJOU**l



Nombre moyen de sessions par jour de la semaine
Mean amount of sessions bv week dav

Tl.e, using command COM. ...nese/days, % see that COM is used while RV is now used for **55%.**

Maintaining 100 hours of TX **files** r all users, together with on-destructive fide **readout,** erefore seems to be universally ppreciated.



Nombre moyen de session par **heure**
Mean amount of sessions by hour

We'll close hereby announcing that e new processing centers will operate on-line data banks with a -day capacity **(DS files)** for all ograms under Standard service. The **AJOUR and TX files will,** of **course,** continue to **exist.**

Thomas **A. Babits**
Argos Service

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LOCATION AND DATA COLLECTION SATELLITE SYSTEM

USER'S GUIDE

NASA·NOAA·CNES

CONTENTS

1. INTRODUCTION

The Argos **system offers** capabilities **for the** satellite-based **location** of **fixed and** moving **platforms, and the collection of** environmental **data.**
Argos is **the result of a cooperate project between the Centre National** d'Etudes Spatiales (CNES, **France),** the National **Aeronautics and Space** Administration **(NASA, USA) and the National** Oceanic **and Atmospheric** Administration **(NOAA USA)**

The objective is to offer a continuous service throughout the Tiros-N/NOAA (meteorological satellites) program, i.e. through 1990 approximately.
The technical and administrative center of the Argos system is Service Argos, part of CNES, Toulouse. All new system applications must, however, be **aPProved by** CNES, **NOAA and NASA, the three agencies that manage the program,**

The Argos system comprises
- platforms, in the form of buoys, boats, balloons, fixed stations and so on, equipped with electronic devices called platform transmitter terminals (or PTTs) for environmental data collection and uplinking to the space segment:
- space segment;
- ground telemetry acquisition and processing stations, the processing center being at Service Argos, Toulouse:
- the results distribution system.

2. GUIDE TO CONTENTS

This new edition of the Argos Users Guide aims to provide potential system users with Important technical and administrative information.
Use it to
- study the feasibility of envisioned application in the light of similar programs already undertaken and the general nature of the system;
- identify the most appropriate hardware, for both the transmission of data and acquisition of results:
- estimate the cost of a project as far as use of the Argos system is concerned: (the cost of transmission and receiving equipment depends on the supplier and ultimately therefore on the user's choice):
- facilitate administrative procedures when formally requesting approval for a program.

However, this Guide does not propose to grve detailed technical specifications of data transmission and reception herdware, nor of the space segment, *nor* of the data processing software. Such information is to be found m documents referenced in the Guide, and which may be obtained by applying directly to Serwce Argos.
The user WILL find m this Guide
- a concise overview **of certified PTTs that can be** received **and located** by **the** Argos **system (chapter** 3);
- **a brief description of the space segment, the accent being on** system performance and its Implications for users (chapter 4);
- a discussion of the Argos ground segment, and, in particular, of how operations at the dp center can be adapted to user requirements (chapter *5);*
- *a* description of how results can be accessed, together with information on the related hardware (chapter 6);
- an outline of the administrative and contractual procedures necessary for obtaining formal project approval (chapter 7),
- a list of abbreviations, an index, and various documents needed when applying to join the system (Annex)

ARGOS

Argos PTTs have already been designed and developed for a wide range of environmental studies, that is, for studies of the sea, land and air, as well as for biological research (animal tracking, etc).

3.1 MARINE PTTs

These can be divided into two types:

- moving PTTs, for example those mounted on drifting buoys, ships, polar buoys;
- fixed PTTs, for example those mounted on moored buoys,

Oceanographic observations are of interest not only in oceanography, but also in meteorology, climatology, glaciology and marine biology, as well as in industries such as offshore oil, fishing and merchant shipping.

PARAMETERS

Oceanographic parameters observed via the Argos system are of two main types, the purely oceanographic, and those relating to the atmosphere.
Each category may then be subdivided by application, for example meteorology (temperature, pressure), ocean dynamics (waves, wind), chemistry (salinity, pollution) and biology.
The first sensors to be used intensively with Argos PTTs were types measuring water surface temperature and atmospheric pressure.
Considerable experience was acquired in marine research during the First Global GARP Experiment (FGGE), during which 300 sensor-equipped buoys were deployed.
Precise pressure measurements are still difficult to achieve however, particularly given the problems in ensuring reliability throughout buoy lifetime,
Measuring near-surface water temperature using Argos buoys is now common practice. The true accuracy of such measurements is still hard to estimate though, since temperature sensors have different time constants and are placed at different sea depths,
Significant research haa been carried out to develop deepwater temperature measurement sensors. The most difficult problem remaining is that of designing a suitable connection between tha buoy and the sensor itself. A number of manufacturers have worked on the problem and have produced sensor chains of up to 1 50 m that have operated ai sea for up to several months.
Other physical parameters such as air temperature, air-water temperature differences and ambient acoustic levels have been investigated experimentally using Argos PTTs.
Studies into wave phenomena (amplitude, direction, energy spectrum, etc) have also been performed using Argos PTTs. Buoys dedicated to wave studies and equipped as Argos PTTs are now available in two versions, moored or drifting.
Measurement of wind speed and direction has also been studied, The main problem here ia to design an anemometer reliable and sturdy enough to withstand the marine environment. A second problem is how to interpret measurements that, inevitably, are often made below the level of wave crests,
Surface current speed and direction data are obtained by tracking drifting buoys.

DRIFTING BUOYS

Drifting buoys normally have similar . basic characteristics. They comprise a cylindrical tube (the spar), a biconical float protected by an elastic belt, and an antenna protection cone at the top. The batteries, PTT electronics, sensors, etc are housed in the metal or plastic spar (see figure 3.1 .A).
Currently available buoys of this type have proven reliable in all marine conditions, In addition, an operating life of a year or more is now common, thanks to careful design, manufacture and handling. Of the 368 buoys deployed during the FGGE, 263 operated for more than six months, 177 for more than one year, and 56 for *more* than 18 months.
For the most part, the chief interest for oceanographers resides in buoys tracking.
in the wake of these first results, new types of drifting buoy have since been developed,

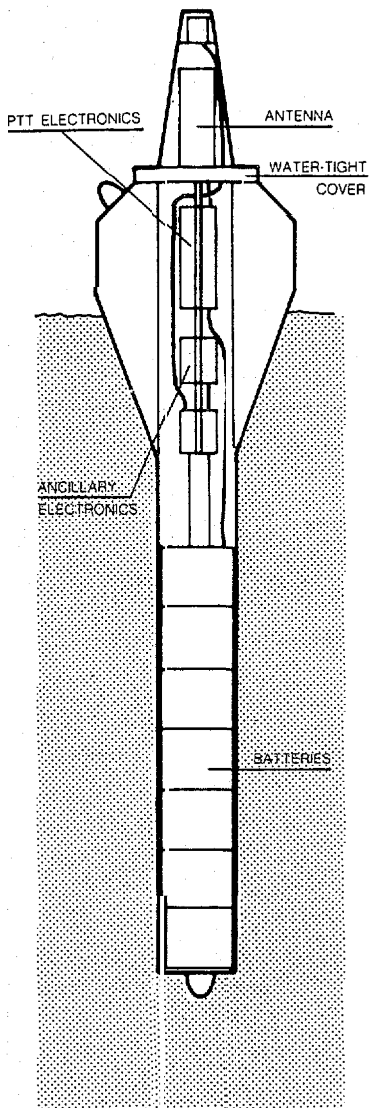


FIG. 3.1.A : DRIFTIN G BUOY

incorporating, for example, a greater number of sensors. This means that certain buoys can transmit not only pressure and temperature data, but also other data such as wind speed and direction Others again have been fitted with rigid sails that help optimize their speed in following winds

Buoys equipped with canvas window-blind drogues (see figure 31 .B) are particularly suitable for studying surface currents, especially in areas where ship-based observation is impracticable. Although drifting buoys are generally set adrift by research vessels, merchant ships and even container carriers are also used to this end. Finally, buoys are sometimes released from aircraft by parachute with no noticeable reduction in performance.

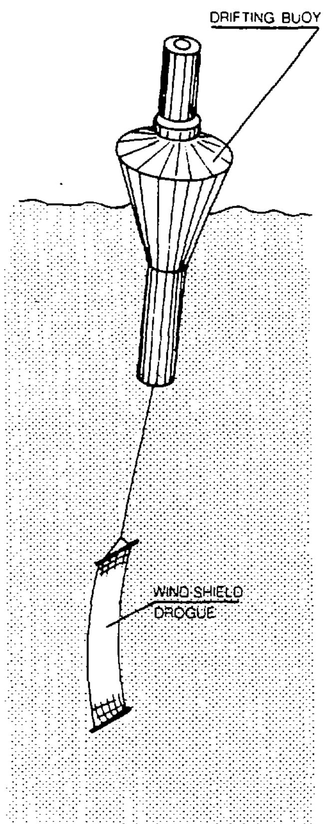


FIG 3 ! B DRIFTING BUOY WITH DROGUE

SHIPS

Some *7000* ships participating m the World Weather Watch currently transmit meteorological and oceanographic data. The present system has two weak points however :

- measurements must be made and transmitted manually, which means that no data are recorded when the operator is not at his post;
- data transmission is mainly earned out by sending HF radio signals to coastal stations, leading to unreliable and offen saturated links at synoptic measurement times.

The Argos system is considerably more efficient and versatile. Three broad types of equipment can be used.

- Automatic stations. Compact, self-powered, water-tight and simple to set up, these stations house meteorological sensors, PTT electronics, antenna and lithium batteries or solar cells m a single unit. Such systems overcome both the problems mentioned above, but the number of observable parameters is strictly limited.
- Manual systems. (See figure 31 C). These have been developed so that a greater number of parameters can be transmitted The data ere entered manually via a keypad, and *some* of the usual procedures are slightly modified. Data transmission reliability is thus considerably Improved. Hardware normally takes the form of an external antenna linked to a single package. The latter, located inside the ship, contains the keypad and PTT electronics.
- Semi-automatic systems. These hybrid systems permit automatic data acquisition from internal sensors, and the entry of more complete data via a manual keypad, Thus, complete messages can be transmitted during operator working hours, end messages of a more restricted nature during the rest of the time.

Greater use of Argos PTTs on board ships is presently being recommended by the World Meteorological Organization. It should be stressed that this system can be used not only for the transmission of meteorological-oceanographic observations. but also for that of date useful to shore-based shipping fleet managers (ship-owners, charterers, etc).

ICE BUOYS

The use of Argos PTTs on ice in polar regions is becoming increasingly common. The aim is to track ice movement and thereby study the risks of collision with oil drilling rigs and shipping.

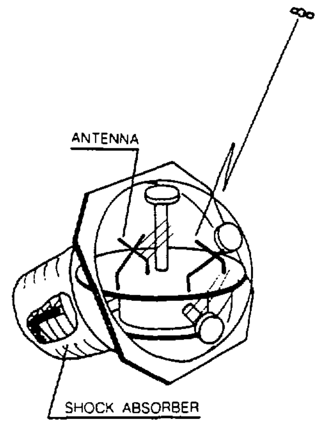


FIG 31 D ICE BUOY

These buoys can be deployed by a variety of means, including helicopter. light aircraft and parachute They are designed to withstand temperatures as low as -50° C. Powered by lithium batteries, the PTTs have a life of more than two years.

Ice buoys are sometimes equipped with satellite navigation receivers that compute iceberg positions extremely accurately. The Argos PTT is used simply to transmit the position, but is also useful es back-up in the event of main system failure.

MOORED BUOYS

The need for environmental data in specific locations over long periods of time has led to buoys being moored in the open **seas** **(see** figure 3.1 C).

The method used with conventional moored buoys is to record data for subsequent manual retrieval. Unfortunately, this frequently revolves loss of data due to recording errors or the impossibility of locating and recovering the buoy. These buoys are also heavier than the drifting variety, since they

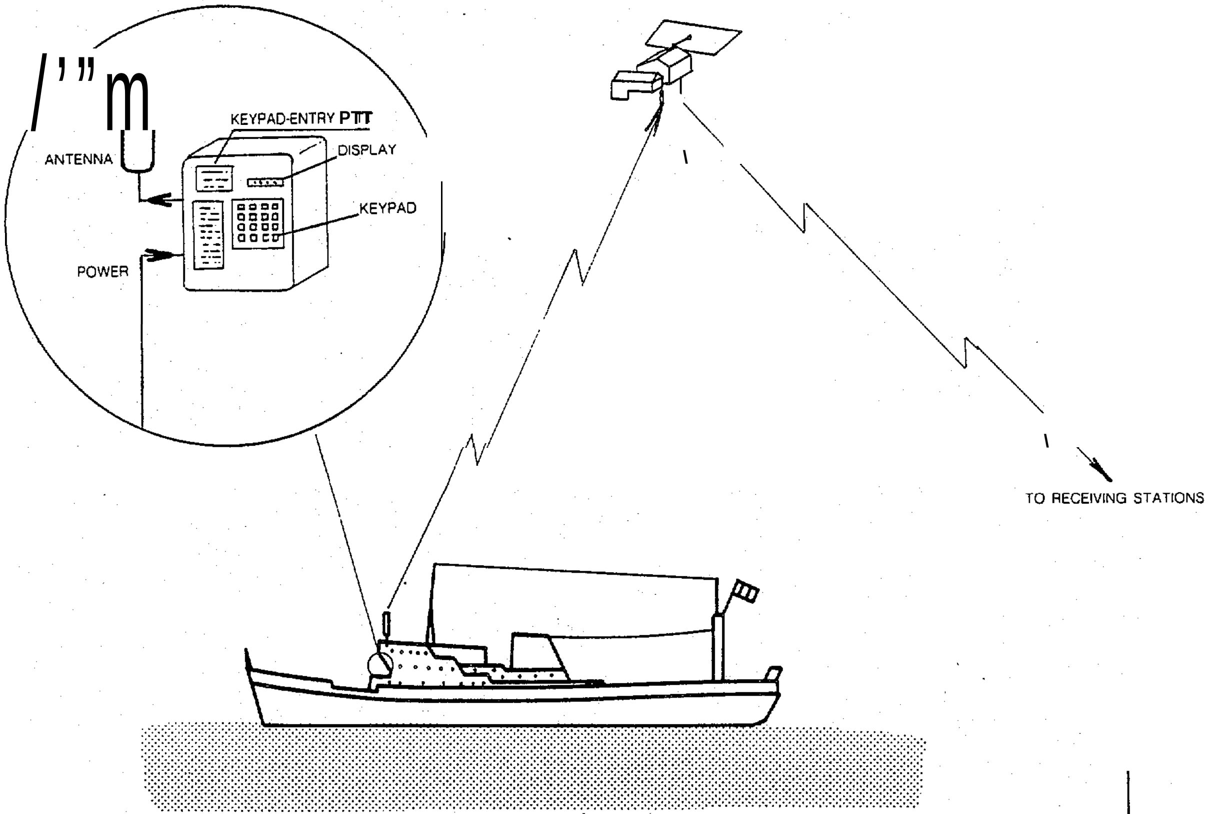


FIG. 3.1.C : KEYPAD-ENTRY TERMINAL PTT ON BOARD SHIP

must support an anchor chain and be able to withstand more buffeting. Their loss involves not only a high financial cost, but can also create a hazard to shipping. Used in conjunction with Argos PTTs, such buoys can be readily located and their data automatically transmitted. Fixed buoys of very different shapes are now commonly used in experimental and operational Argos programs. Masts supporting wind and air temperature sensors can give several meters extra height above the water surface.

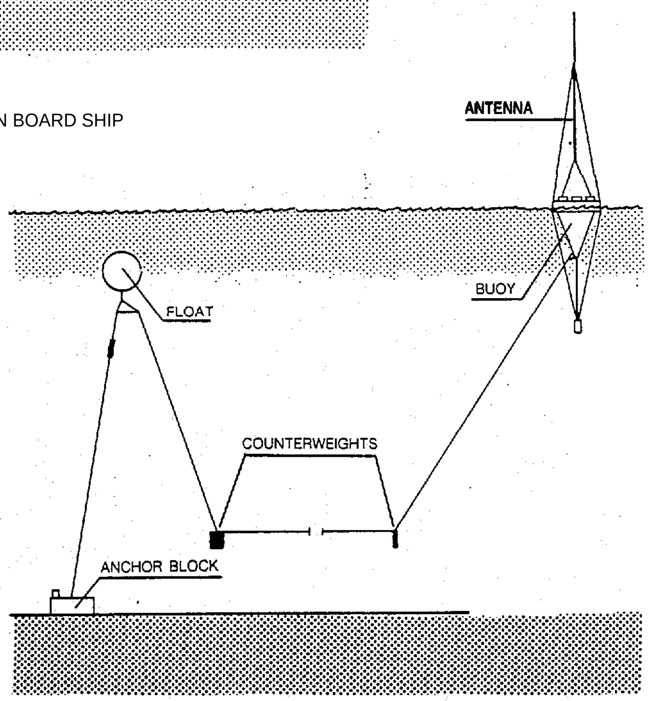


FIG. 3.1.E : MOORED BUOY

3.2 LAND PTTs

Land-based observation stations using Argos PTTs have been developed for many different applications
A typical installation comprises
- standard PTT electronics;
- sensor Interface electronics,
- various sensors;
- antenna,
- dc power supply (rechargeable or disposable batteries) and possibly a panel of solar cells for battery recharging,
- a structure Supporting both Instruments and the PTT

However, each new use of the system calls for the development of a new type of station
In addition to conventional meteorological stations measuring pressure, temperature, and wind speed and direction, several new specialized stations have been developed in areas including
- snow data,
- hydrology,
- volcanology. seismology. etc.

METEOROLOGICAL STATIONS

Following a comparative study mto the use of geostationary and polar-orbiting satellites for the collection of meteorological data, the World Meteorological Organization concludes that both were valid
The fact remains, however, that at very high latitudes (North and South polar circles) data collection by geostationary satellite is Impossible in areas such as Alaska Greenland, the Arctic and Antarctic, Argos is the only feasible system
Sensors used with Argos-equipped meteorological stations normally need to meet fairly stringent specifications Parameters transmitted tend to be the same as those in conventional land-based meteorological stations, that is, atmospheric pressure, temperature and dew point, wind speed and direction, and so on

SNOW DATA STATIONS

Avalanche prediction and the measurement of the rainfall equivalent of snow-cover water levels for reservoir management are performed thanka to networks of automatic measurement stations designed specifically to meet the rigors of remote high.mountam locations.
The Argos system permits the transmission of data recorded m locations too Isolated to be integrated into telephone networks and too. hemmed in for satisfactory surface VHF hnks
The main measurements made at these stations are
- depth of snow cover, measured by an ultrasonic sensor, by which the precipitation equivalent and progressive packing of the snow cover can be estimated;
- wind speed, measured by an anemometer .
- air temperature, measured under a shelter
- the vertical temperature profile of the snow cover.

StatIons often house a microprocessor which manages station operation and can, for example, compute average values (data compression).
The PTT is haused m a watertight case buried under the snow — a good thermal insulator

HYDROLOGICAL STATIONS

River basin management can be modernized by equipping hydrological stations with Argos PTTs
These stations are normally equipped with limnographs and rain gauges, but other parameters such as temperature can also be measured
Argos PTTs for this type of application are powered by either batteries or solar cell panels.
Since the number of daily satellite passes is insufficient to enable river level variations to be monitored, hydrological stations are often equipped with electronic memories,
Hydrological stations transmit messages of 256 bits each, which can be broken up mto sixteen 16-bit words, for example
- 14 words representing water depths measured at regular intervals;
- one word representing total rainfall:
- one word representing the time of the last measurement

3.3 BALLOONS

Complex physico-chemical phenomena in the various layers of the atmosphere can only be measured and studied "in Situ"
Very long flight time balloons capable of staying aloft for several weeks or even months and carrying instruments weighing around 50 kg open up the possibility of data collection on a global scale
Balloon tracking is performed by the Argos system which also receives physical parameters measured by the balloon-borne Instruments
A particularly difficult problem is that of the great differences in temperature that occur within the same day at these altitudes. One possible solution is to stabilize the balloon s volume by pressurization so that its envelope becomes stable.

The stratosphere is the layer of atmosphere between 15 and 40 kilometers
Stratospheric balloons are kept aloft by their helium or hydrogen filling gas, or by air heated by terrestrial radiation. Because of their considerable volume, they are usually not only fragile, but also difficult to manufacture, to transport and to launch.

The Argos PTT must be thermally insulated so that it can resist the temperatures of -30 to -80° C that prevail in the stratosphere.

TROPOSPHERIC BALLOONS

Tropospheric balloons have been developed for use in studies of the middle and lower reaches of the atmosphere. Designed to fly at altitudes where air density is constant, their lifetime is inevitably limited by atmospheric and geographical conditions
These superpressure balloons float at a constant altitude (assuming constant atmospheric pressure) day and night.
Tropospheric balloons are fitted with sensors that measure temperature, atmospheric pressure, humidity and balloon internal pressure.

MANNED BALLOONS

The Argos system has been used experimentally for the tracking of long-duration manned balloon flights, for example the flight Tokyo-San Francisco in Double Eagle V.

3.4 ANIMAL TRACKING

Efforts to study and protect certain animal species call for information as to their distribution and migration. A number of satellite-based programs have been undertaken to track dolphins, basking sharks, leather-back turtles, whales, birds and wild pigs. Perfecting the use of Argos in animal tracking is an on-going activity.

Typical technical problems posed by this type of work are tha following :

- short duration of satellite visibility; unsatisfactory propagation characteristics;
- difficulties in developing PTTs that can withstand the high pressures and mechanical forces encountered in tracking marine
- **relatively** short battery lifetimes (though this can be increased when tracking marine species by fitting a switch that turns the PTT oft when the subject is diving, and by using solar cells when tracking land animals);
- the weight of the PTT which must be negligible in relation to the animal's *own* weight.

3.5 CERTIFIED **PTTs**

User platforms must be equipped with a PTT type certified by Service Argos.
PTT message structure and RF characteristics are described in § 4.3. Two basic Parameters to be borne in mind here are that the mean location accuracy of the Argos system is around 500 m, and that messages to be transmitted have a maximum length of 256 bits per transmission.
A list of manufacturers of Service Argos-certified PTTs appears in an Annex to this guide.

There are two basic categories of PTT :

- location types, equippad with good quality oscillators, used for both location and data collection;
- data-collection-only types, equipped with lower quality oscillators.

4. SPACE SEGMENT

The space segment of the Argos system comprises two NOAA satellites in simultaneous low-altitude orbit
These satellites are equipped with the Argos Data Collection and Location System (DCLS) which receives and processes all transmissions from the PTTs in visibility during a pass

Each time a satellite passes over one of the three telemetry ground stations forming part of the Argos ground segment, all recorded data are downlinked

4.1 NOAA/TIROS-N SATELLITES

The satellites carrying the Argos DCLS are the NOAA (National Oceanic and Atmospheric Administration) polar-orbiting spacecraft of the Tiros-N series the first of which was launched on October 13. 1978
Funded by NOAA. Tiros-N satellites are procured and launched by NASA (National Aeronautics and Space Administration) Operations are managed by NOAA s National Environmental Satellite and Data Information Service (NESDIS)
The original Tiros-N was an R&D prototype Thera then followed a series of satellites, each designated first by a letter and then by a number after successful launch NOAA-A thus became NOAA-6 while NOAA-C became **NOAA.?**

The present ATN series (Advanced Tiros-N) is an extension of the original Tiros-N program. The first ATN satellite to be launched was NOAA-E, successfully put into orbit on March 8.1983. and subsequently named NOAA-8 Tiros-N/NOAA satellites, as shown in figure **4 1 A, comprise three elements**
The Equipment Support Module (ESM) is a five-sided box-like structure The widest side carries earth-pointing antennas and sensors. including the DCLS antenna. The other four, all the Same size, accommodate thermal louvers
The Reactlon Support Structure (RSS), at one end of the ESM module Includes the last stage injection motor, an attitude control propulsion system and the boom-mounted solar array The solar cell panel. t 16 m^2 in area, is motor driven to rotate once per orbit so that it continuously faces the sun during the daylight portions of the orbit
The Instrument Mounting Platform (IMP), at the other end of the ESM module, is a highly stable instrument mounting platform supporting the attitude control sensors and the mam earth observation instruments. The Attitude Determination and Control Subsystem (ADACS) manages antenna pointing and satellite attitude, the latter to within 0.2° of the geographic references.

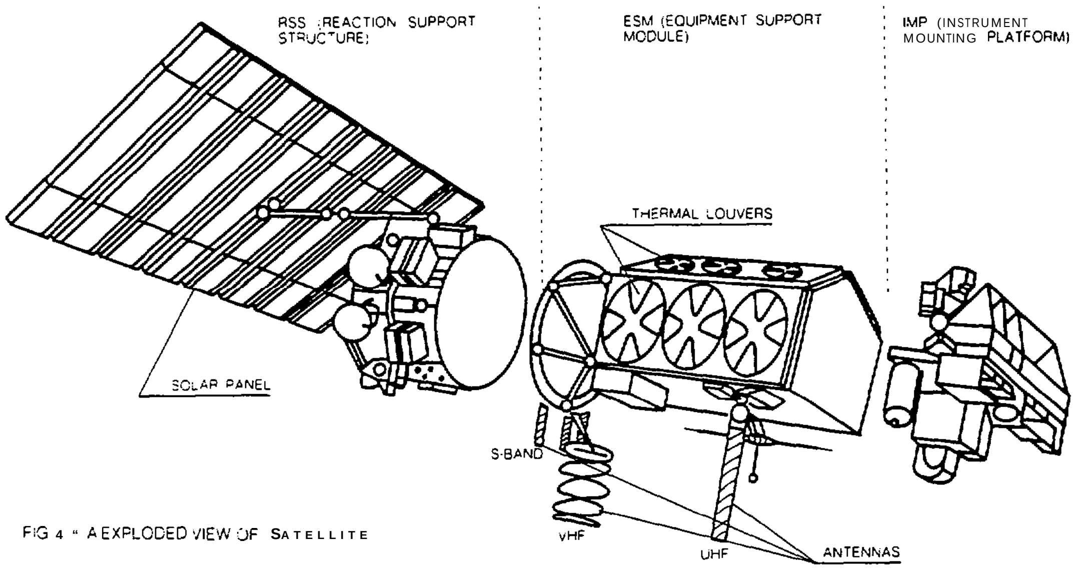


FIG 4 " A EXPLODED VIEW OF SATELLITE

4.2 SATELLITE ORBIT

The orbit of a satellite is its trajectory about the earth, Characteristics of the orbit selected for NOAA/Tiros-N satellites are as follows :

- Circular orbit
- Altitude: 830 km ± 18 km, and 870 km ± 18 km for the two satellites respectively.
- Polar orbit: the satellites see both tha North and the South polea once each orbit. Inclination (angle between equatorial and orbital planes) is 98.7°.
- Sun-synchronous orbit: this means that the orbital plane rotates about the polar axis at the same speed as the earth about the sun, that is, one complete rotation a year. Each orbit therefore transects the equatorial plane at fixed local solar times. From the user's point of view, this means that a given PTT comes into satellite visibility at the same local solar time every day.
- Period (the *time* taken to complete one orbit): approximately 101 minutes.
- Number of orbits per day: approximately 14 for each satellite,

This choice of orbit guarantees complete coverage of the earth surface. The orbital planes of the two satellites are mutually offset by 75°. Orbiting altitudes are also different so that the period of one satellite's orbit is approximately one minute longer than that of the other%. This ensures that a given point on the earth is not seen at the same instant by the two satellites.

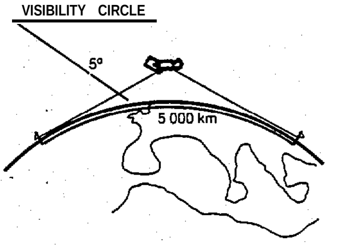


FIG. 4.2.A

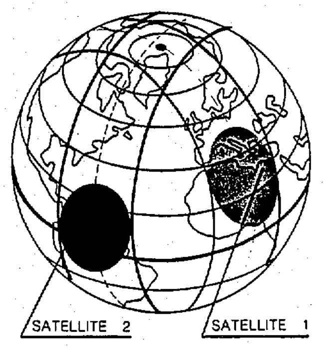
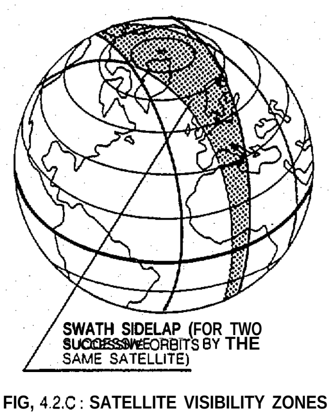


FIG. 4.2.B



FIG, 4.2.C : SATELLITE VISIBILITY ZONES

Visibility zones for data collection

As figure 4.2.A shows, each satellite simultaneously sees all PTTs within a 5000-km-diameter circle for a minimum elevation angle of 5° (where the elevation angle is defined as the angle between the horizon and the satellite-PTT line of sight).

As the satellite orbits, the visibility zone, centered on the satellite ground track, it sweeps a swath 5000 km in width encompassing the earth and passing over the North and South poles. (See figure 4.2. B).

As a result of the earth's rotation, two successive swaths (that is, from one orbit to the next) are separated by 25° of longitude, the second ground track being to the West of the first, At the equator, this represents some 2800 km. There is therefore an element of sidelap between two successive swaths. (See figure 4.2. C).

Since satellite orbits are al an angle of 8° to the polar axis, the ground tracks of two successive passes cross each other at a latitude of approximately 82°.

Pass frequency and duration **of visibility**

Sidelap increases with latitude. The number of daily passes over a given PTT also depends on latitude. At the poles, the satellites see all PTTs each at every pass, thai is, 28 times a day in total. Pass duration, however, is independent of site latitude. The normal cut-off point for estimating pass duration is an elevation of 5° above the horizon. The mean duration for pass is about 10 minutes, while that of zenith pass is 13 minutes

The most significant pass **characteristics are given below. The figures relate to both satellites,** but in the event of a PTT being **seen simultaneously (high latitudes), only one pass is taken into account**

PTT LATITUDE	CUMULATIVE VISIBILITY OVER 24 HOURS minutes	MINIMUM NUMBER OF PASSES PER 24 HOURS	MEAN NUMBER OF PASSES PER 24 HOURS	MAXIMUM NUMBER OF PASSES PER 24 HOURS
0“	80	6	7	8
± 15°	88	8	8	9
± 30°	100	a	9	12
± 45°	128	10	11	12
± 55”	170	16	16	18
± 65”	246	21	22	23
± 75°	322	28	28	28
± 90°	364	26	28	26

4.3 ONBOARD EQUIPMENT

UPLINK

Any platform used in conjunction with the Argos system must be equipped with a certified PTT for uplinking messages to the satellite

Frequency
The nominal frequency of all PTTs is 401.650 MHz Receive frequency is measured by the onboard package and the Doppler shift determined.

Message format
Message format and structure are described *m* the table below. The message consists of the following sequence :

- 160 milliseconds of unmodulated carrier, to allow the Argos onboard receiver to lock onto the carrier:
- a 15-bit preamble to synchronize the Argos onboard equipment with the message bit rate;
- an 8-bit format synchronization word, followed by one spare bit and 4 bits defining sensor data length (the number of 32-bit blocks);
- the PTT Identification (or ID) number, assigned by Service Argos and encoded by 14 bits;
- 6 error check bits;
- 32 to 256 bits of sensor data, in steps of 32: if sensor data processing is to be performed by Serwce Argos, encoding and format must comply with certain rules laid down in § 5.3

UNMODULATED CARRIE? LENGTH T1	MODULATED CARRIER LENGTH T2					
	PREAMBLE	FORMAT SYNC	INITIALIZATION	NUMBER CF 32-BIT GROUPS	:D N“ (+ Check bits)	SENSOR DATA
T1 = 160 ms ± 2.5 ms	15 bits (= 1)	8 bits (00010111)	1 bit (= 1)	4 bits	20 bits	N × 32 bits (1 < N < 8)

PTT MESSAGE STRUCTURE AND FORMAT

Modulation

The modulation used for data transmission is split-phase/PM. The unmodulated carrier corresponds to the phase reference. Figure 4.3.A gives the eight format synchronization bits (000101 11).

ARGOS DCLS

The DCLS receives the messages transmittal by PTTs within view of the satellite. Since this is a random access system (that is, encoded PTT messages are received on a random basis), the received signal is a mixture of all the messages transmitted by the PTTs within the visibility zone. The DCLS attempts to accommodate a maximum number of messages, but the number of processing channels available is limited. Message separation in time is achieved through asynchronization of transmission and the use of different repetition periods, and separation in frequency through the Doppler shifts of the various PTT carrier frequencies. The DCLS comprises:

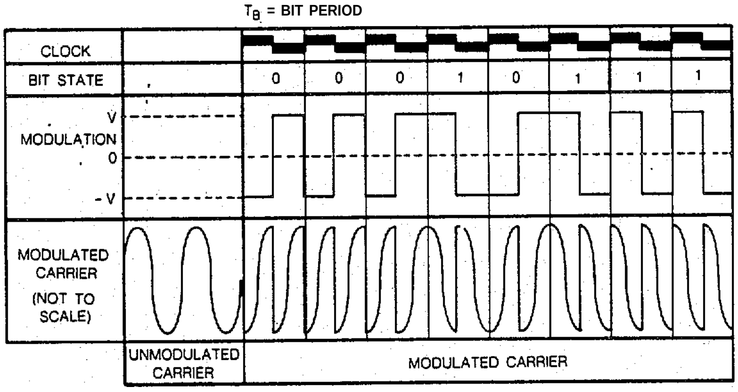


FIG. 4.3.A : SIGNAL MODULATION

- power supplies ;
- processing equipment: four identical units in parallel, each **processing one message at a time (provided these are separated in frequency); a control unit;** a telemetry encoder; a buffer memory;
- **the receiver section, comprising a receiver proper and a search unit, each being duplicated to** ensure adequate redundancy.

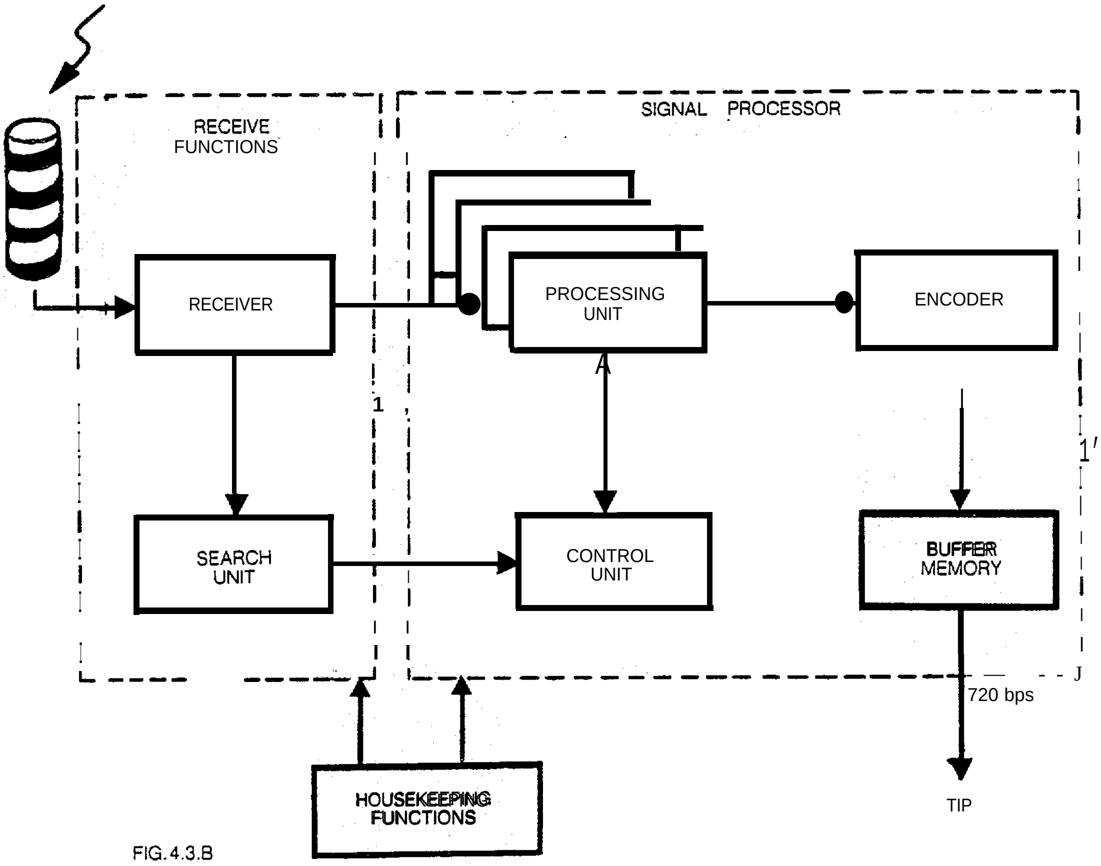


FIG. 4.3.B

Each processing unit comprises :
- a phase lock loop for rapid frequency and phase Synchronization on the unmodulated section of the message;
- a bit synchronizer which generates a clock signal at the appropriate bit rate and also performs signal restitution;
- a Doppler counter for determination of receive frequency;
- an encoder-formatter which generates telemetry messages in digital form PTT ID number, sensor data, measured frequency and time and date of measurement.

The processed message is transferred to the satellite telemetry encoder. known as the TIP (Tires Information Processor)
A buffer memory is used to maintain a constant telemetry transmission data rate of 720 bps.
The Argos data flow is mixed with flows from other low-data-rate experiments on **board** the satellite **in the** TIP processor, which transmits at a combined rate of 8320 bps, 720 bps being reserved for Argoa data

SYSTEM CAPACITY

The capacity of a satellite-based data collection system is usually defined as the maximum allowable number of data collection platforms (DCPs) that can transmit data through the system.
For a data collection system (OCS) on board a geostationary environmental satellite **Such as** GOES or Meteosat. the capacity is easy to assess because :
- all DCPs are permanently in view of the satellite;
- each self-timed DCP transmits at a regular assigned time:
- each self.timed DCP is allocated a constant time slot for transmission;
- each DCP is assigned a transmission frequency chosen from a fixed number of channels

Transmission time and frequency are assigned in order to prevent interference, and hence to ensure that each message is relayed The maximum number of allowable DCPS can then be calculated simply by multiplying the number of frequency channels by the number of time slots.
The Argos data collection and location system differs from a geostationary DCS in that
- at any given instant, only 3 4% Of the earth's surface is viewed by the satellite, therefore only a limited number of PTTs can be received by the DCLS;
- PTT transmission repetition periods are randomly distributed between 40 and 200 s;
- message duration is also randomly distributed, but between 0.36 and 0.92 s:
- **transmission frequency is the** same for all PTTs, but receive **frequencies are randomly distributed because of the difference m Doppler shifts associated with a random distribution of PTTs on the earth;**

The main consequence of these differences is the nsk of non-acquisition of a PTT message, due either to interference from simultaneous transmission producing the same receive frequency, or to non-availability of a DCLS processing umt since only four messaqes can be acquired at a time

The "system use factor" is defined as the mean rate of arrival of messages at the receiver From the user viewpoint, system performance can be judged on the basis of two parameters :
- the elementary probability **Of** massage acquisition;
- the bit error probability m the sensor data part of the message

These two parameters relate back to the system use factor Various simulation tests on the Argos onboard package have provided useful information as to message acquisition probability. For an acquisition probability of O 8, the **package can simultaneously handle**
. up to tOOO (data-collection.only) PTTs with a transmission period of 200 s and message duration of 0.35 S (32 bits),
- **Up to** 75 (location) PTTs with a repetition period of 40 s and message duration of O 92 s (256 bits).

Message acquisition probability is, of course, Improved by repeating the message several times during the same pass
For example, for an elementary probability of message acquisition of 0,8, the probability of message reception becomes O 9920 for a message repeated three times and O 9999 for a message repeated six times.
As to bit error probability, trials have confirmed the expected value 104, that is, one erroneous bit in 10,000 This percentage can be further reduced by ground processing operations when several Identical messages are transmitted and received during the same **pess This is because the processing software automatically compares** all messages received **(see § 53)**
To summarize, it is clearly in the user s interest to deploy PTTs that repeat messages several times

4.4 DOWNLINK

As figure 4.4.A shows, the Argos DCLS data are multiplexed in the TIP processor and then transmitted to ground via threa downlinks :

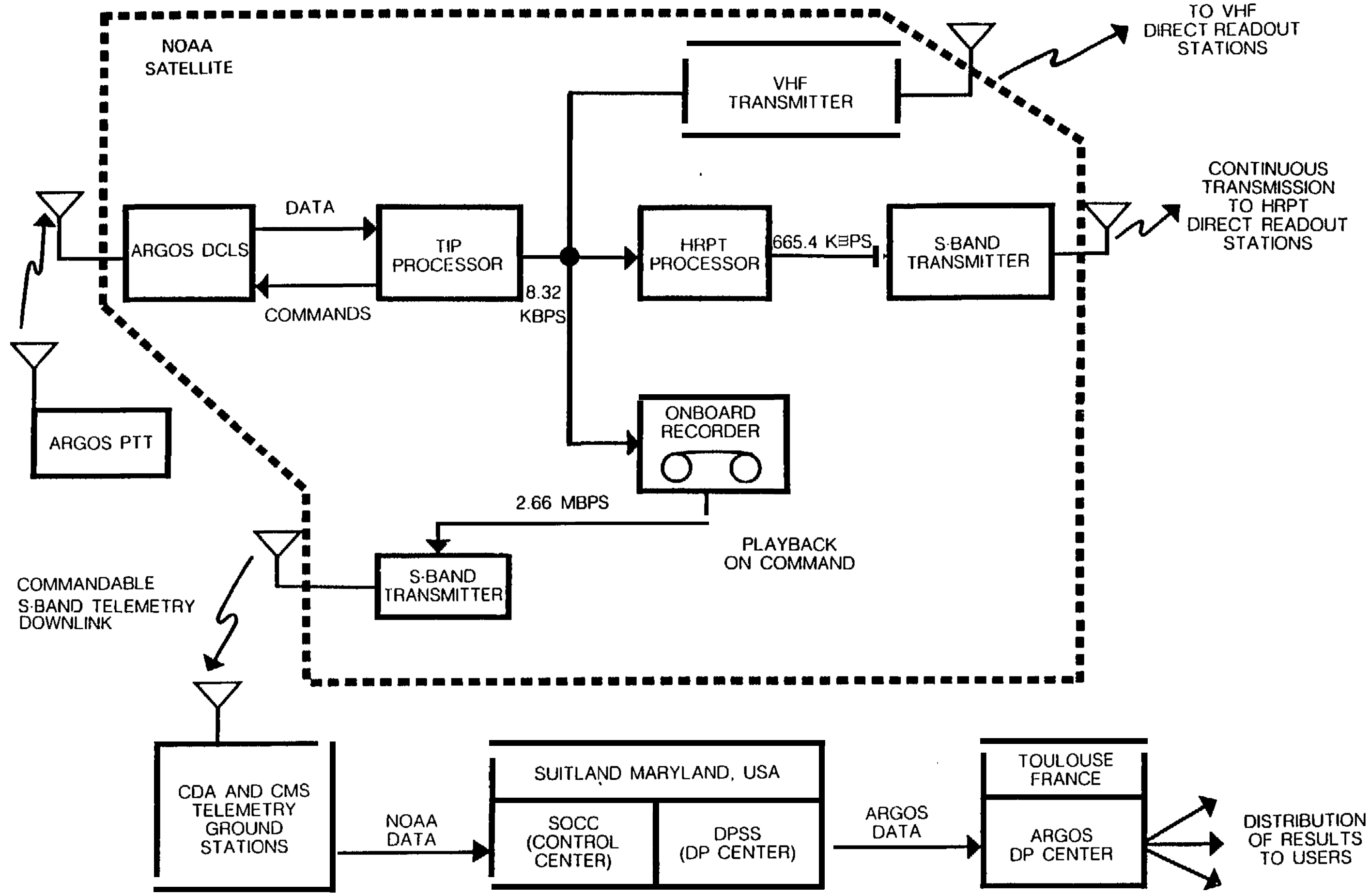
- real fima : the TIP output (8320 bps) directly modulates an onboard VHF direct readout transmitter which **transmits continuously on S-band;**
- real time : the TIP output is multiplexed on board the satellite with High Resolution Picture Transmission data and transmitted continuously;
- e offline : the TIP output is also recorded by one of the onboard tape recorders, and each time the satellite passes over one of the telemetry ground stations, the data on tape are read out and transmitted to ground via the S-band telemetry playback downlink.

Characteristics of the three links are summarized below:

SUMMARY OF DATA TRANSMISSION LINK

LINK	CARRIER FREQUENCY (MHz)	SIGNAL SOURCE	DATA RATE (kbps)	MODULATION	TRANSMISSION POWER [W)
VHF Real-time	136.77 or 13777	TIP	8.320	Split-phase/PM	1.0
S-band Real-1 ime	1698 or 1707	HRPT	665.4	sptit-phase/PM	5.25
S-band playback	**1698** *or* **1702.5 or 1707**	**Data recorders**	**2661.6**	NRZ/PM	**5.25**

FIG. 4.4.A. ARGOS DATA FLOW DIAGRAM
(SCHEMATIC)



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5. THE ARGOS GROUND SEGMENT

5.1 TELEMETRY ACQUISITION

TELEMETRY GROUND STATIONS

(see figure 5,1 .A)

The National Environmental Satellite and Data Information Service (NESDIS, USA) currently operates two Command and Data Acquisition (CDA) stations, one on Wallops Island (Virginia, USA) and one at Gilmore Creek (Alaska. USA). A cooperative agreement between NESDIS and the "Centre de Meteorologic Spatiale" (CMS, France) provides for the reception of TIP data at Lannion (France).

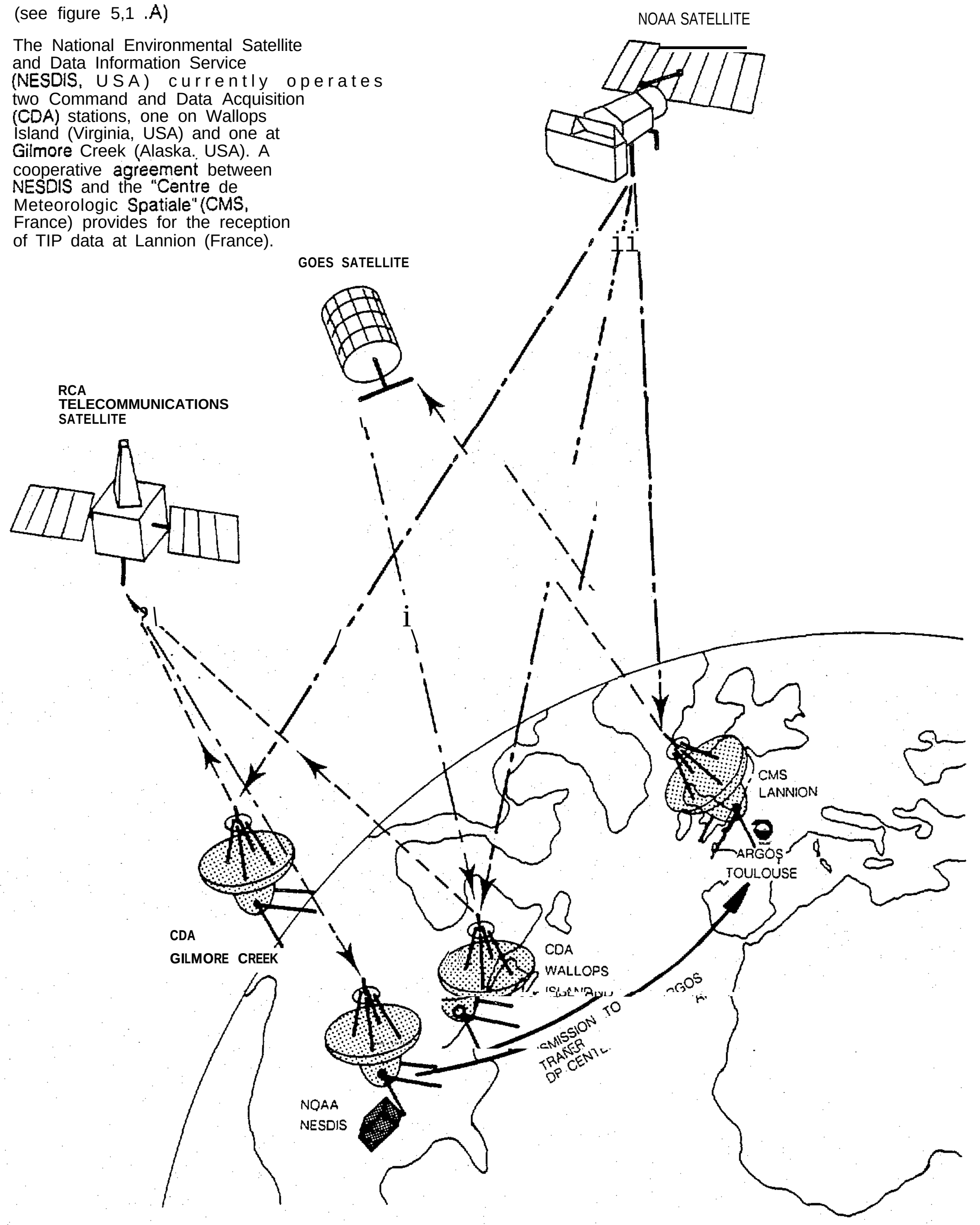


FIG. 5 1.A TELEMETRY TRANSMISSION

The CDA and Lannion stations relay the data received to the NESDIS data processing facility in Suitland (Maryland, USA) via geostationary satellites (commercial satellites for the CDA stations and GOES for the Lannion CMS station). Thanks to these three stations, the satellites do not lose contact with the ground for more than one orbital period per day.
In Suitland, Argos data are separated from the data of other experiments and transmitted to the Service Argos dp **center in Toulouse** via a permanent **hnk.**

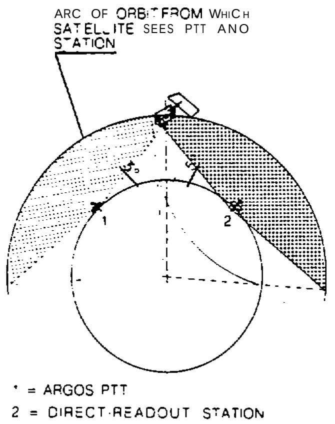


FIG. 5 1 B

DIRECT READOUT STATIONS

Also known as "local user terminals" (LUTs), these are receiving stations set up by users for real-time access to data continuously retransmitted by the satellite. VHF direct readout stations receive Argos data transmitted by the onboard VHF telemetry transmitter, whale S-band direct readout stations receive them multiplexed with HRPT data.
A direct readout station can receive satellite transmissions when the ground track is within 2500 km of the station.
The station receives PTT transmissions when both it and the PTT are within satellite visibility. For this, the PTT visibility circle (radius 2500 km) and that of the direct readout station must overlap.

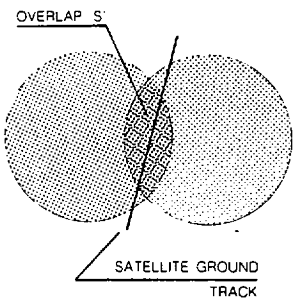


FIG. 5.1 C

(See figure 5.1 .B). This overlap is labeled S in the figure.
Station efficiency can be assessed by considering the ratio 'e' of the number of messages received by the station to the number received by the satellite.
This ratio is simply equal to SiSl, where S1 is the area of the PTT visibility circle and S the overlap of the two circles (See figure 5.1.B)
As figure 5. 1.D shows, the ratio depends on the distance between the receiving station and the PTT

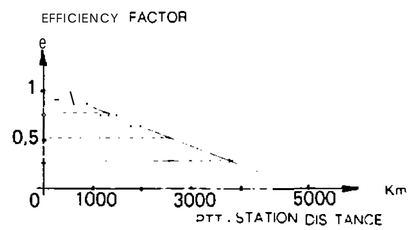


FIG 51 D EFFICIENCY FACTOR OF A DIRECT READOUT STATION

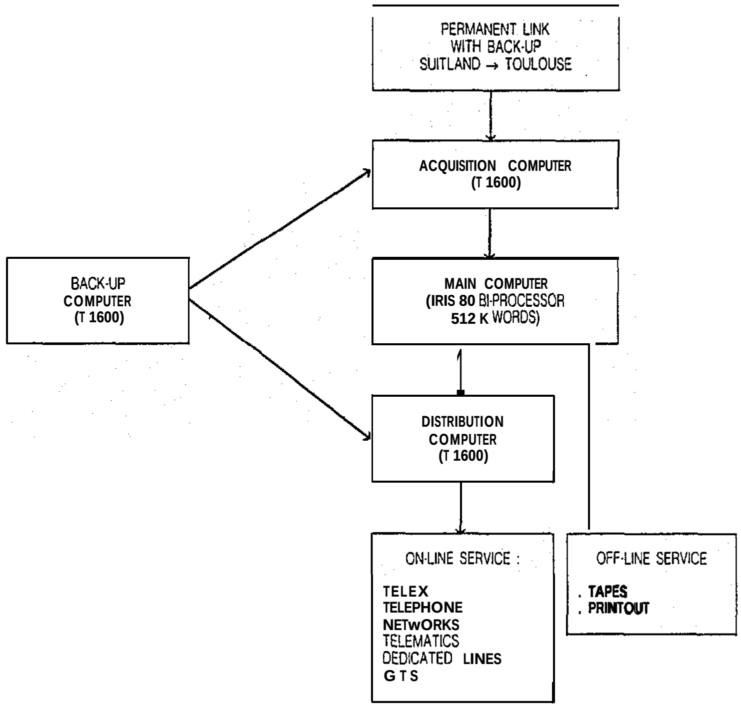
5.2 THE ARGOS DP CENTER

Operating 24 hours a day, 365 days a year, the Argos dp center aims at maximum availability and minimum data loss
Argos data are received and recorded on a Télémécanique T 1600 acquisition computer, connected by a high-speed (4800 - baud) hnk to the main computer, a CII-Honeywell Bull Iris 80 bi-processor Real-time preprocessing by the Iris 80 includes the following operations :

- management of data flows;
- separation of PTT data from DCLS auxiliary data;
- processing of auxiliary data under the control of DCLS technological parameters;
- sorting of messages by PTT
- sensor data processing:
- location calculations;
- creation and updating of results files.

Real.time distribution of results is performed by a T 1600 which handles dissemination and dialogue with users,
Reconfiguration of hardware can be simply and swiftly Implemented, so interruptions to service are minimized.
Naturally, maintenance and updating operations, tests aimed at Improving the 'real-time" software, and certain breakdowns can result in some delays in making results available However, all data are saved, so no loss occurs.

THE ARGOS DP CENTER



5.3 **SENSOR** DATA PROCESSING

The three elements of sensor data processing are :

- preprocessing;
- standard processing;
- special processing.

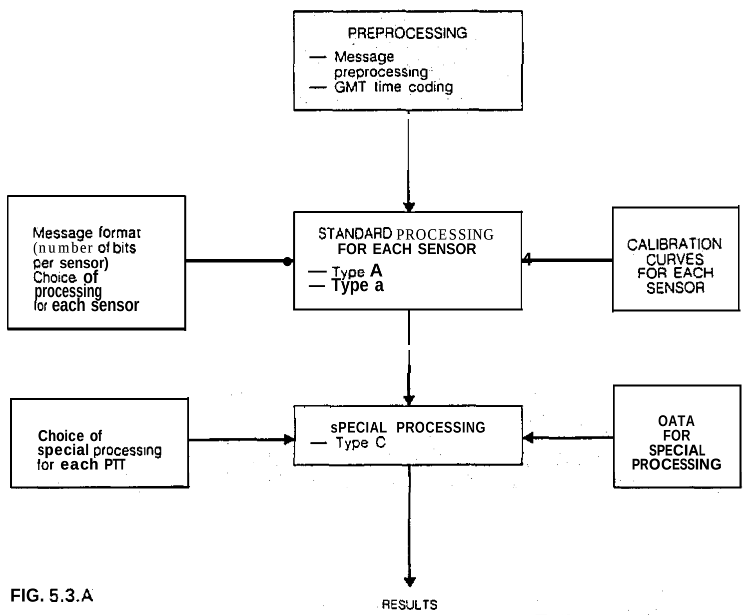


FIG. 5.3.A

MESSAGE PREPROCESSING

- **Data compression**

This procedure concerns PTT sensor data contained m the same telemetry flow

Messages are processed in chronological order This means that they are compared on a message-by -message.bit-by-bit basis. The last message of an identical series is then saved, together with its hme-coding and a figure de fining how many messages were m the series. This figure is known as the "compression Index"'

When a user finds that a PTT message has been received with a compression index greater than 1, he can be confident that all data transmitted are correct

- GMT Time coding

Message processing by the Argos onboard package revolves the time-coding of message acquisition by the DCLS clock

This time-codmg consists in replacing satellite time-coding for each message by the corresponding GMT time Standard time.coding is available to the user with a standard resolution of one second. A more precise service for data-collection-only PTTs is also available *on* **request The error then drops to less than 12 ms**

STANDARD SENSOR DATA PROCESSING

Data from different sensors of a single PTT are processed independently. A different processing option can therefore be chosen for each sensor, but it **is not possible to choose multiple options for the same sensor.**

There are *two* types of **standard processing**

Type A processing converts PTT sensor data into user-defined digital codes. The table below shows the various processing possibilities offered by the Argos dp center according to the type of sensor data encoding.

Type B processing converts primary received data into user-defined physical units, using a sensor-specific calibration curve (See figure 5.3.B)

STANDARD OPTIONS

OPTION	RECEIVED DATA	PROCESSED DATA
A1	BINARY	DECIMAL
A2	BINARY	HEXADECIMAL
A3	BINARY	OCTAL
A4	BCD (BINARY CODED DECIMAL)	DECIMAL

Such calibration curves are supplied to Service Argos by the user.

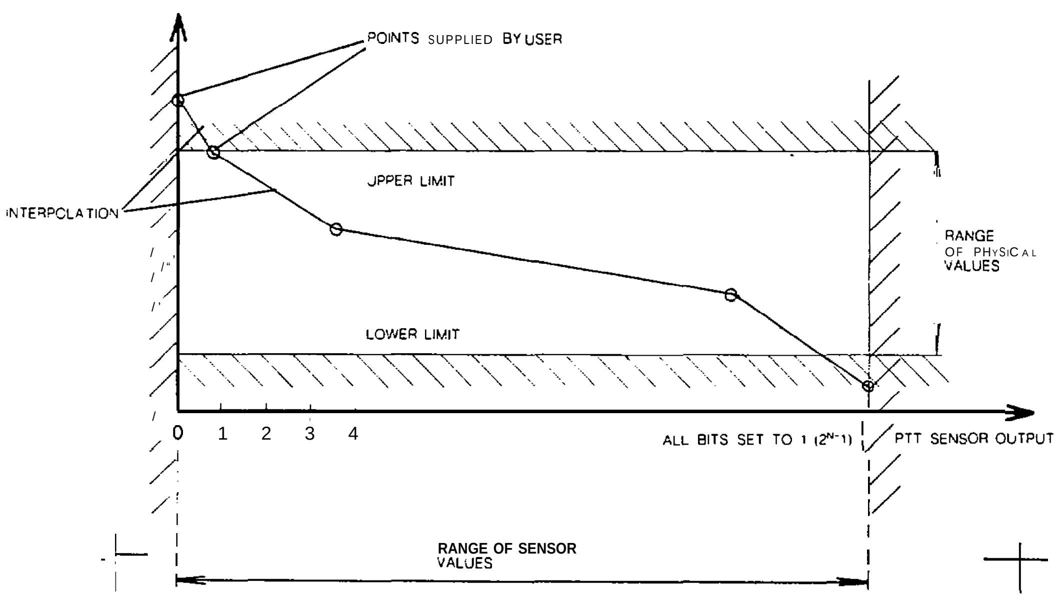


FIG 5 3 B SENSOR CALIBRATION CURVE

They should be in tabular form, and defined by a maximum of 20 points. Processing itself consists essentially in linear interpolation between the tabulated points of the curve. Output data, to five significant figures, are made available in the standard "floating point" scientific notation.
Examples:
- pressure measurement in millibars:
  1011.2 mbar → p = .10112 E + 4
- temperature in degrees Celsius :
  22.322 °C → t = .22322 E + 2

Type B processing opens up the" possibility of permanent sensor quality control for any PTT. The user first specifies an upper and **lower limit** in physical values for each sensor. The measurement from each sensor can then be checked against these limits, and data supplied to users will show a question mark (?) after any sensor value outside limits.

SPECIAL PROCESSING

Special processing programs can be selected for specific PTTs and applications, but certain programs such as types C5 and C6 are suitable for a range of applications. For any given **PTT, one and only one type of special processing may be selected;**

Type C5 special processing

This type of processing arose from the use of keypad terminals developed by Service Argos. The keypad is typically used for the entry of meteorological data in the appropriate WMO code. Sensor data are in 256-bit BCD (binary coded decimal) form. Type C5 processing converts these BCD data into meteorological messages compatible with the GTS (Global Telecommunications System).

Type C6 special processing

With this type of processing, the sensor calibration curve is represented as a simple polynomial form. The sensor's response can be compensated by the output from a second sensor, the compensation function also being a polynomial function.

Special processing software can also be developed to meet specific user needs.

5.4 LOCATION CALCULATIONS

THEORY OF OPERATION

Platform location is determined by calculation of the Doppler effect on receive frequencies. Transmission frequency being fixed for ail PTTs, it turns out that the satellite receive frequency at any instant can be used to define the field of possible positions for a PTT. The field is in the form of a half-cone, with the satellite at its apex, the satellite velocity vector as axis of symmetry, and the apex half-angle (A) such that:

$$\cos(A) = \frac{(fr - fe)}{fe} \cdot \frac{c}{V}$$

where :
c = speed of light
V = satellite speed relative to PTT
fe = transmission frequency (401 .650 MHz)
fr = receive frequency.

For each Doppler measurement, one location cone is obtained. Now, the altitude of the PTT forms part of a sphere, the "altitude sphere", and is known. (See figure 5.4.A). The intersection of the various location cones with the altitude sphere thus gives two possible positions of the PTT, which are symmetrical with respect to the satellite ground track. (See figure 5,4. B).

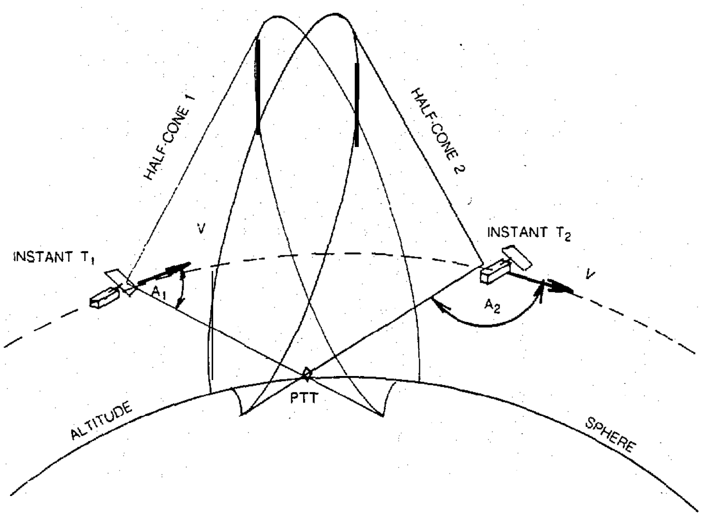


FIG. 5.4 A

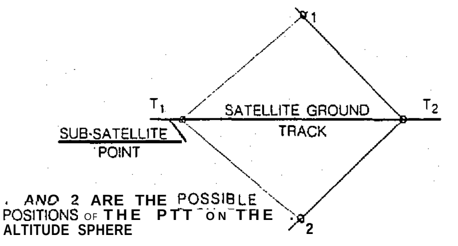


FIG. 5.4.B : LOCATION CALCULATIONS (GEOMETRY)

To find which of the two positions is correct. additional information is required. for example previous locations, range of possible speeds etc.
Other information required for location determination using the Doppler effect includes satellite orbit parameters and precise time-coding of measurements.
Satellite orbit parameters are obtained by 11 orbitography PTTs. These are at accurately known geodetic locations. (See figure 5.4. C). Equipped with very stable oscillators, they yield orbital parameters on a daily basis and permit extrapolation on to the next day's orbit. The system presently permits determination of satellite position to within 300 m in the ground track direction, and 250 m in the cross-track direction. (See figure 5.4 C).

A "time-coding" PTT featuring high-precision time" coding and extreme frequency stability (cesium clock) is located in Toulouse. It is used to monitor the stability of the onboard oscillator and to align all measurements with the same time scale (GMT) with a mean precision of 12 microseconds

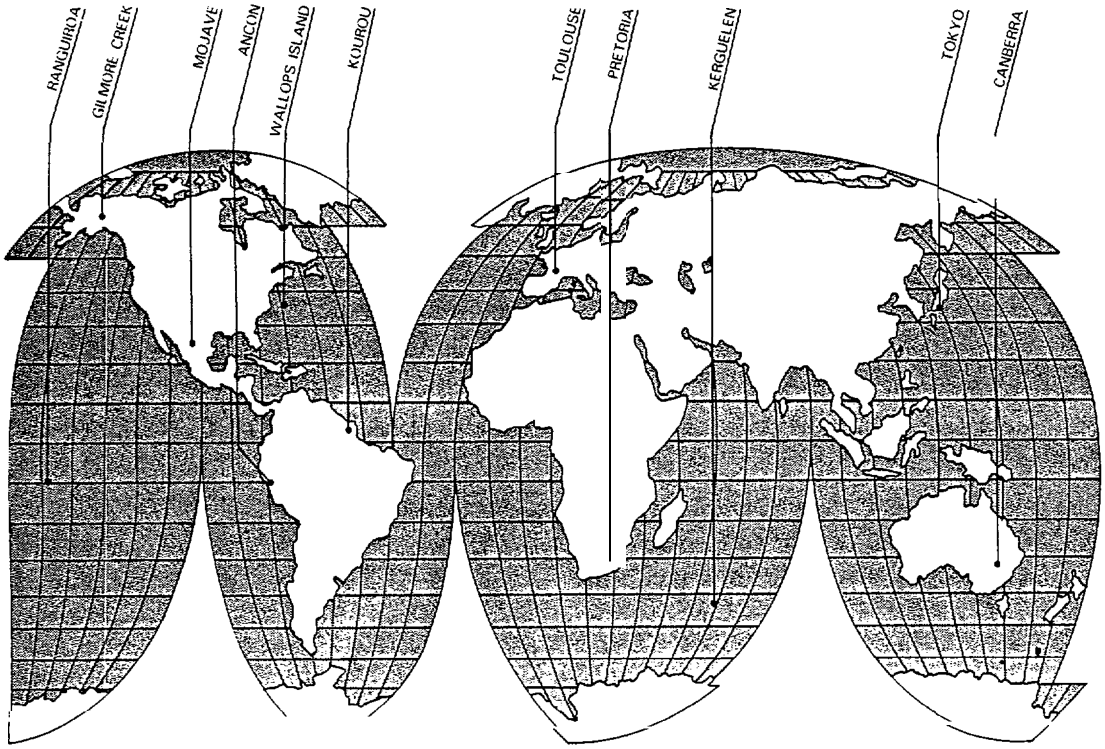


FIG 5 4 C ORBITOGRAPHY PTTs

OPERATIONS

Before calculations proper are performed, certain geometric tests are earned out to eliminate any PTTs for which an acceptable accuracy cannot be guaranteed. In the event of the various conditions remaining unsatisfied, location is not attempted. On average, 33 % of PTTs received during a satellite pass are eliminated by this test.
When location is eventually performed, results are subjected to quality control.
The main causes of rejection after location calculations are

- excessive frequency deviation : more than 24 Hz difference between average transmission frequencies in two passes for the same PTT is considered unacceptable:
- unsatisfactory convergence : in the great majority of cases, this results from a "noisy" PTT oscillator;

the **rejection threshold for short-term instability during a pass is** 4.1 0"5;

- **unacceptable distance from** ground track; experience shows that positions determined for PTTa that are either too close to or too **far from the ground track are inaccurate. (See figure** 5.4. D),

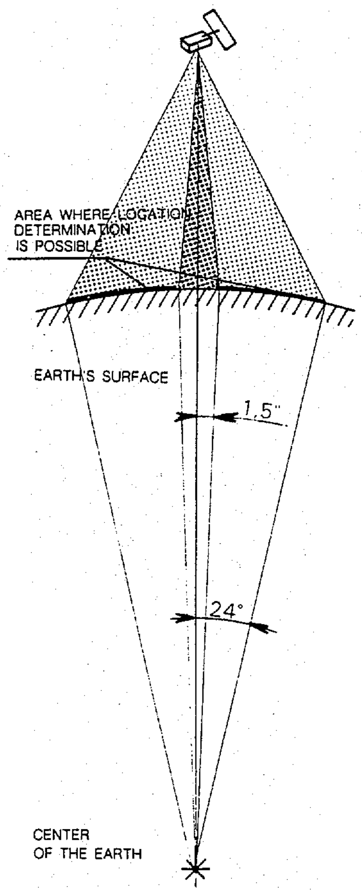


FIG. 5.4.D : "LOCATION ZONES"

PERFORMANCE

Number of locations per day
Figure 5.4.E shows the mean number of locations per day as a function of PTT latitude,
Service Argos guarantees a minimum of six locations a day with the two satellites in service and three a day with one satellite.

Location accuracy

Sources of error are of two sorts.
1) Errors related to Service Argoa, that is, inaccuracies as to satellite orbit and time coding of measurements.
2) Errors related to PTTs. The main factors involved are PTT altitude, oscillator stability, and platform movement.
Errors associated with PTT altitude only take on real significance in the case of balloons.
Oscillator atability is important in the short, medium and long term.
The short term is defined as up to 100 milliseconds, and concerns the duration of message transmission. Short-term instability leads to inaccuracy in the calculation of the Doppler effect and results in random error in location calculations. If short-term stability is worse than 10^{-8}, the message is ignored by the satellite and neither data collection nor location are performed.
The medium fern?, defined as 20 minutes, relates to **the** duration of PTT visibility. Medium-term instability results *in* frequency drift during the satellite pass and thus leads to inaccurate location calculation, The main cause is temperature variation during the pass. In general, the necessary stability can be readily achieved by placing e standard oscillator in

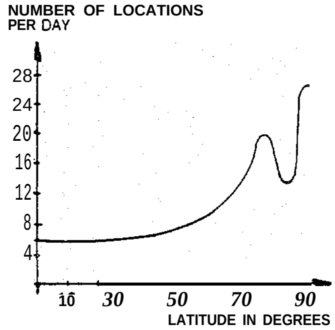


FIG. 5.4.E : LOCATIONS PER DAY

a suitably insulated housing (made of polystyrene, for example).
Service Argos requirements call for a stability of 2.10^{-7}, corresponding to location to within several tens of kilometers. The table below shows performance figures as a function of medium-term stability.

The long term is defined as the period separating two satellite passes over a given PTT, or approximately 100 minutes, Long term instability is compensated for in location calculations if it does not exceed 10^{-6}.
The PTT is considered to be stationary at the moment of transmission. Therefore, any movement can result in error, a speed of 1 m/s leading to a. location error of the order of 200-300 m.

MEDIUM TERM STABILITY		ACCURACY IN METERS	
%	in Hz/inn	in 65 % of cases	in approx. 95% of cases
2.10^{-9}	0.04	150	500
5.10^{-9}	0.10	500	1300
10^{-8}	0.20	1100	2000
2.10^{-8}	0.40	2100	3600
5.10^{-8}	1.00	4000	6000
10^{-7}	2.00	5500	9000
2.10^{-7}	4,00	approx. 50km	
$> 2.10^{-7}$		calculation aborts	

5.5 RESULTS

FILE CREATION

The Argos dp center performs sensor data processing and location calculations in parallel. When the two operations for a given telemetry flow are over, the complete results are brought together in elemental files known as "DISPOSE",

Each file contains the output data from one PTT. Files are stored on tape at the rate of one tape a day, and are added to the Argos data bank which contains three months of data.

"DISPOSE" files then undergo three operations :

- data compaction, to produce the "TELEX" (TX) file;
- updating, to produce the "AJOUR" (AJ) file;
- meteorological encoding, by which TX and AJ files are adapted to GTS requirements,

Data compaction means retaining the most useful or meaningful sensor data message from each PTT for each flow,

The choice is made according to three criteria, which are, in order of importance :

- the index of message quality (NQ) : the messages chosen are those for which all sensors are within limits;
- the compression index (NF), or the number of identical messages : the message(s) with the highest index are selected;
- satellite message reception time and data : to resolve, the most recent message is chosen,

The resulting file is called the "TELEX" (TX) file,

Updating is performed to produce a general file known as «AJOUR» containing the last TX file received for each PTT in the system,

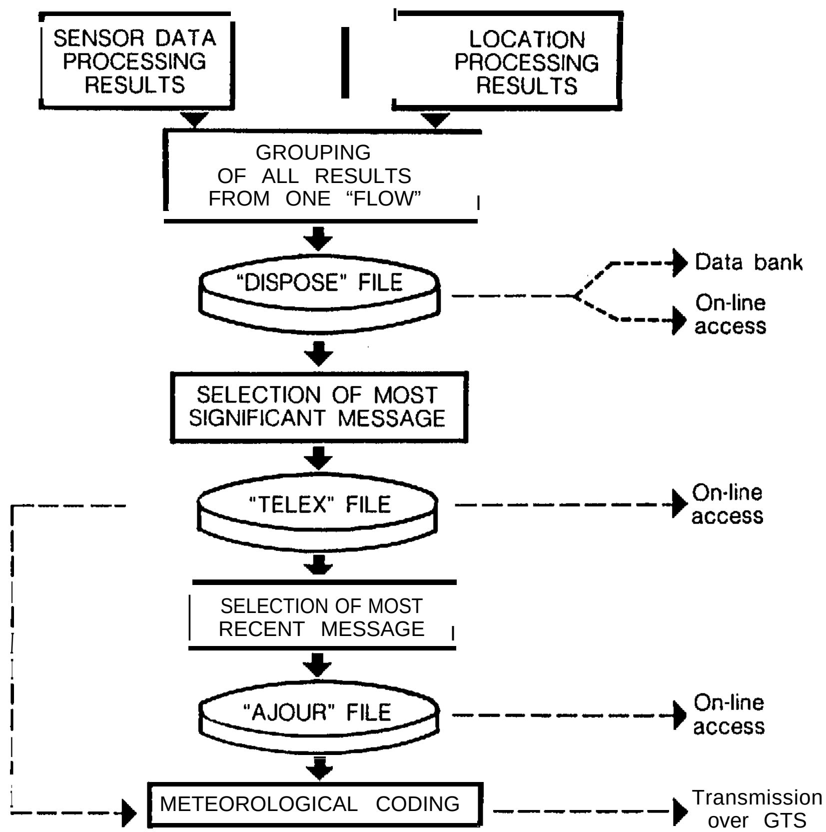


FIG. 5.5 A : FILE CREATION

FILES

The user can access three types of file :

- the "AJOUR" file, containing the most recent location and sensor message for each PTT;
- the "TELEX" file, containing, in chronological order, one sensor message and corresponding location per satellite pass for each PTT;
- the "DISPOSE" file, containing, in chronological order, all location data and all sensor messages for each satellite pass and each PTT.

6. RESULTS DISTRIBUTION SYSTEM

6.1 DISTRIBUTION OVER THE GTS

THE GTS

The Global Telecommunications System is a system for the exchange of meteorological data between the Weather Services of all countries. It originally arose from the setting up of the World Weather Watch, a basic program of the World Meteorological Organization (WMO). The system's prime function is to forward data towards the various national meteorological centers,

The GTS is organized on three levels:

- world level;
- regional level;
- national level,

Three World Meteorological Centers (WMCs) located in Washington DC, Moscow and Melbourne are interconnected via the main trunk circuit. On this circuit, Regional Telecommunications Hubs (RTHs) are responsible for communications between the main trunk circuit and national centers.

The Argos center is directly linked to the Paris RTH (See figure 6.1. A),

WMO CODES

To be transmitted over the GTS, data must be formatted according to certain codes published by the WMO. Each code relates to a particular area such as land stations, marine stations (buoys and boats), hydrological stations, and so on.

SYNOP code
This code is used for the transmission of data from fixed land-based stations.

SHIP code
This is used to transmit surface observation reports from stations or ships at sea.

HYDRA code
Used for data from hydrological stations.

DRIBU code
Originally developed for the Southern Hemisphere Drifting Buoy System which was, in turn, part of the First Global GARP Experiment (FGGE), this code is now used internationally in connection with buoys.

CONDITIONS FOR ACCESS

The GTS is reserved exclusively for the transmission of weather data. The type and format of these data are subject to general international agreements and, in certain cases, also to bilateral agreements.

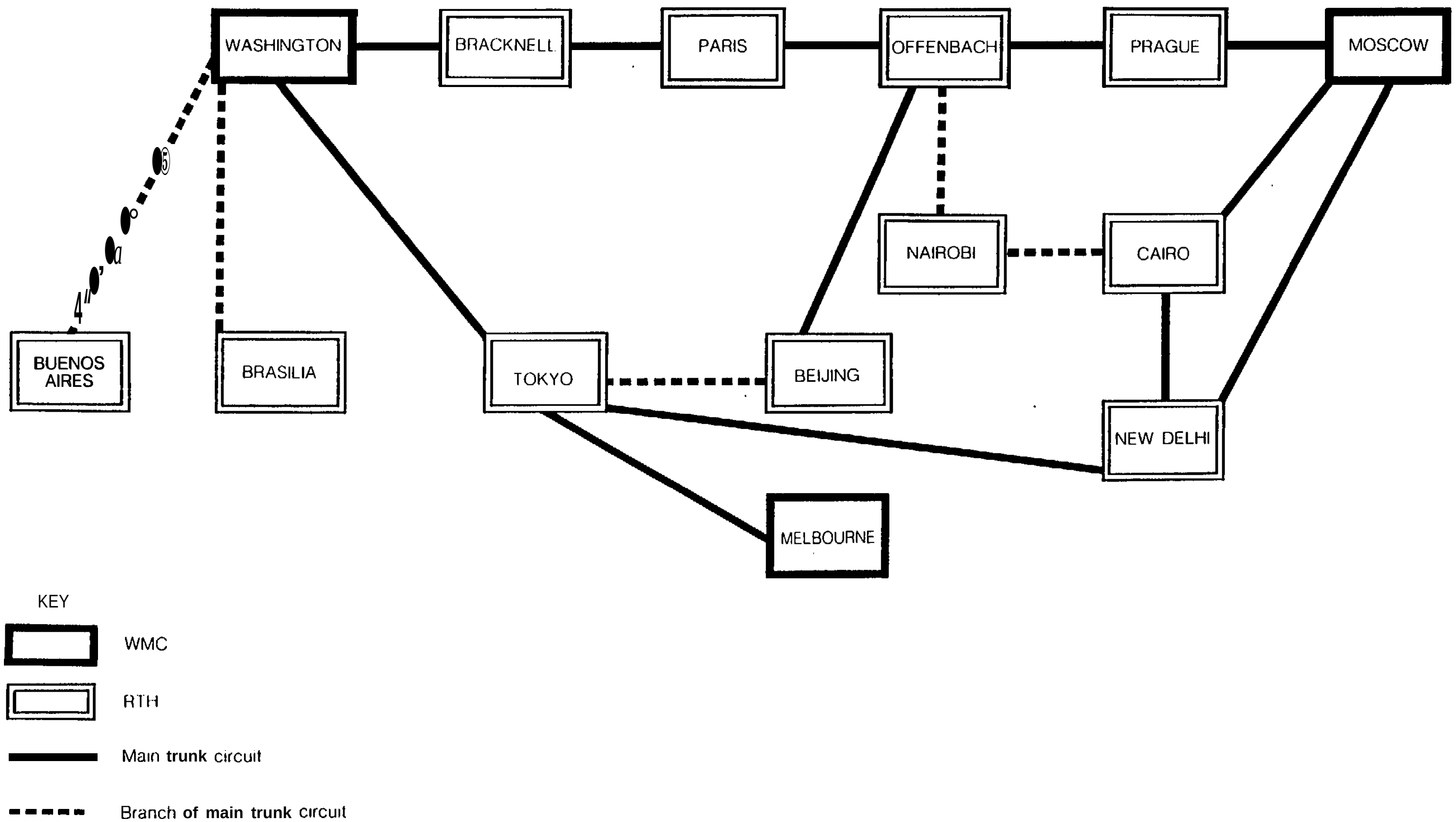
The conditions for transmission of Argos data via the GTS are :

- formal approval of the program by Service Argos;
- the existence of an appropriate GTS transmission code;
- existence of appropriate software for Service Argos to convert data into this code;
- agreement between the national Weather Service of the user's country and the French national Weather Service, the DMN (Direction de la Météorologie National),

Transmission of PTT data
When everything is ready from the technical and administrative aspects, it is up to the user to declare his PTT operational and ask Service Argos to arrange for transmission via the GTS.

Service Argos then transmits to the DMN and confirms this to both the user and the DMN, the only organization with the right to actually insert data on the GTS.

FIG 6 1 A G TS MAIN TRUNK CIRCUIT AND BRANCHES



6.2 DIRECT ACCESS

The difference between data distribution via the GTS and other real-time methods is that in order to access results, the user must call.
There are presently three ways of accessing data files :
- international telex network;
- international telephone network:
- TRANSPAC network,

ACCESS VIA INTERNATIONAL TELEX

To call up data via a teleprinter, the user has only to telex the Argos dp center using standard procedures,
Data transmission rate is 50 baud.

ACCESS VIA TELEPHONE

In Europe, the user needs a modem conforming to European standards. Access is via the Toulouse call number,
In North America, the user needs a modem conforming to US standards. Access is via the Suitland (US) number.
The numbers concerned are reserved exclusively for accessing Argos data. Transmission rate is 300 baud.

ACCESS VIA TRANSPAC

The TRANSPAC network is the French national packet switching data network.
Standardization of access procedures to packet switching networks means that TRANSPAC is now connected to similar networks in other countries via the International Gateway Center (IGC), as indicated in figure 6.2.A.

Two lines (a 300-baud and a 1200-baud) are presently available for Argos use. User access is via one of the following methods :
- telex link (50 baud);
- standard telephone link (300 baud):
- special telephone link (1200 baud);

. dedicated transmission link (direct link 10 a data transmission network).
The advantages of the system are reduced cost, higher output rates and greater security.

Worldwide communication
Users wishing to access their results via TRANSPAC must subscribe to their national network, having checked that the two networks are connected.
Below is a list of a number of countries and networks where access is possible.

Europe:
- Austria (Radio Austria):
- Belgium (DCS);
- Finland (Finpak);
- Germany (Datex-P);
- Great Britain (PSS);
- Greece (Helpac);
- Luxembourg (Luxpac);
- Norway (Norpak);
- Portugal (Datacess);
- Spain (NID);
- Sweden (Telepak);
- Switzerland (Telepac);
- communication via EURONET, an interim network,

outside Europe :
- Australia (Midas and Austpac);
- Brazil (Interdata);
- Canada (Ipacs and Datapac);
- Gabon (Gabonpac);
- Israel (Israpac);
- Ivory Coast (Sytranpac);
- Japan (Venus and DDX-P);
- Korea (Dacom);
- Singapore (Telepac);
- South Africa (Saponet);
- USA (Tymnet, Telenet, Unmet, Autonet).

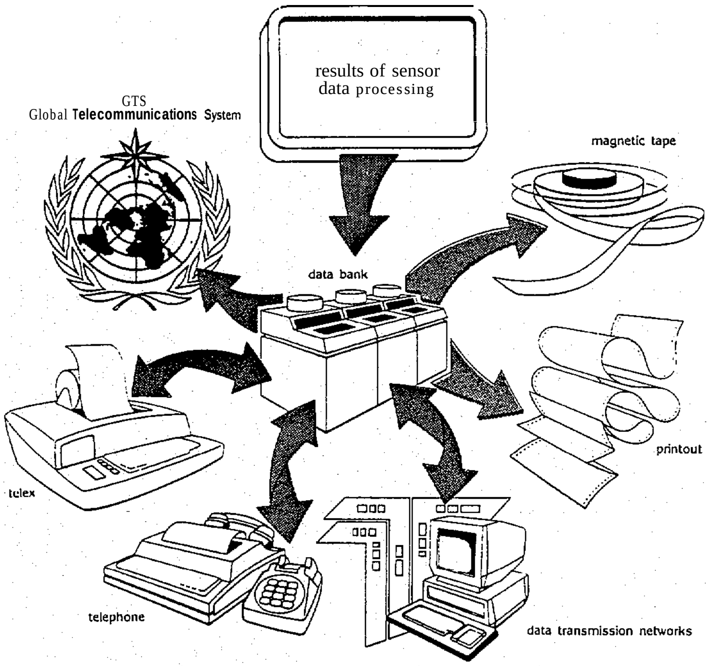


FIG. 62A : DATA DISTRIBUTION

6.3 OFF-LINE DISTRIBUTION

Argos "DISPOSE" files are saved on magnetic tape at the rate of one tape a day, giving 100 tapes in just over three months. They are processed every two weeks as follows
- the last 15 tapes are read by the computer:
- the data are **rearranged by PTT ID N° and then by chronological order for each** PTT;
- **the** data are then transferred to **other** tapes These are sent directly to the user every fortnight or month, or printed out and sent every fortnight. In both cases, the postal service is used.

Data archiving
Service Argos presently archives results for a period of 100 days only
These results can be consulted by users of "standard"' and 'back-up" services (See § 7.2).

Figure 6.3.A Distribution of results

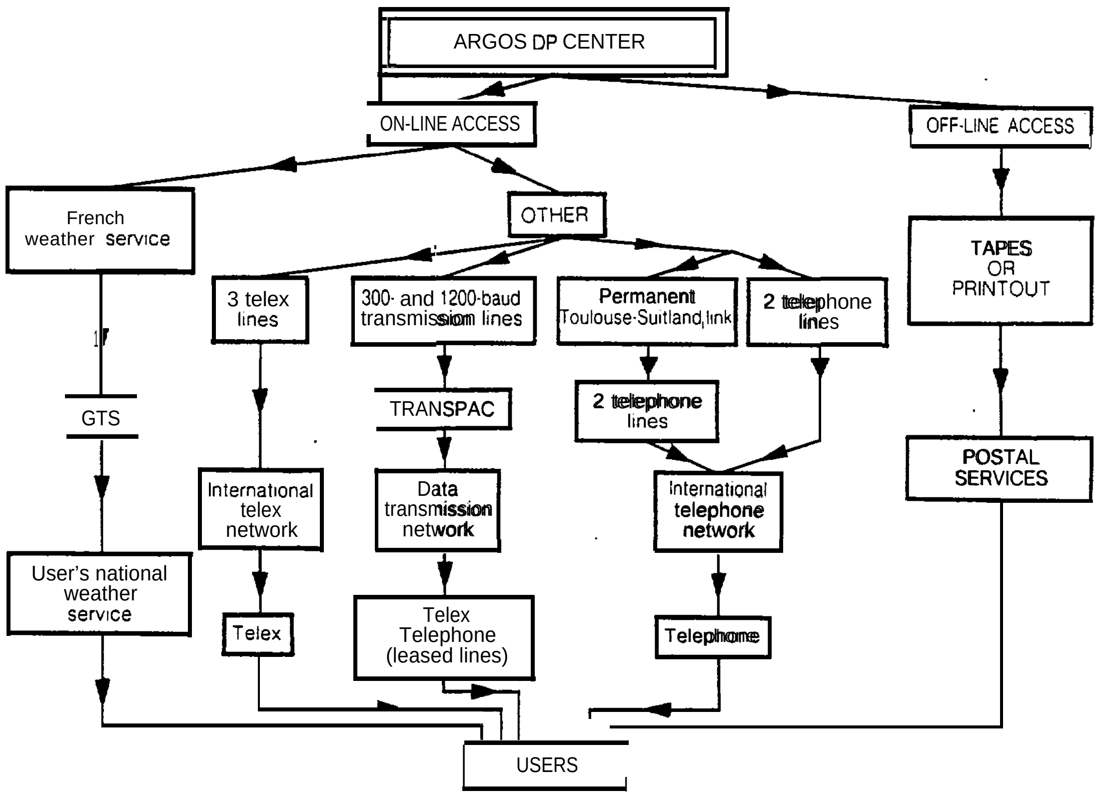


FIG 63A DISTRIBUTION OF RESULTS

6.4 AVAILABILITY OF RESULTS

AVERAGE MONTHLY AVAILABILITY

Service Argos regularly performs statistical checks on hardware availability.
The table below gives availability figures for a recent 12-month period.

	MINIMUM AVAILABILITY %	MAXIMUM AVAILABILITY %	AVERAGE AVAILABILITY %
USA LINK	95.6	100	96.9
ACQUISITION	95.9	99.7	98.5
PROCESSING	91.7	98.3	94.7
DISTRIBUTION	90.2	97.5	94.9
GTS LINK	96.2	100	99.6

However, as far as the user is concerned, the availability of his data at any instant does not depend on these factors, but rather on the availability of distribution facilities. Other availability factors only affect throughput tim° up to the distribution system,
Data flows. are received for processing at the Argos dp center on average every 50 minutes. The time taken for actual processing is 10 minutes per flow.

Hence, processing facility availability is higher than would seem to be indicated by the table, since maintenance and certain breakdowns may occur and be terminated during the 40 minutes between two processing operations and therefore not cause delays.

THROUGHPUT TIME

To understand the problem of acquisition-to-availability throughput time, consider the period between reception of data by the satellite and final delivery to users.
Since one orbit takes 100 minutes and each satellite sees one of the three telemetry ground stations every orbit, the mean interval between reception of data and transmission to a station is 50 minutes.

The next component of system throughput time, the "NOAA component, includes :
- transmission to Suitland by the telemetry ground stations;
- acquisition and sorting of Argos data at NESDIS.

A third component, the "Argos" component, includes :
- transmission from Suitland to Toulouse;
- acquisition and data processing at Service Argos, Toulouse;
- distribution to users via a microcomputer connected to the distribution computer.

The mean time before data becomes available (orbit + NOAA + Argos components) is approximately four hours.
The mean percentages for the number of messages received with given throughput times during a recent 12-month period were :

≤ 1 hr	≤ 2 hrs	≤ 3 hrs	≤ 4 hrs	≤ 6 hrs	≤ 8 hrs	> 10 hrs
3 %	8 %	28 %	52 %	74 %	86 %	8 %

7. ADMISSION TO THE ARGOS SYSTEM

Operations committee
The Argos system is managed by the ARGOS Operations Committee, a bilateral (France/USA) organization made up of representatives of the three participating agencies, namely
- the National Aeronautics and Space Administration (NASA USA);
- The National oceanic and Atmospheric Administration (NOAA, USA);
- The Centre National d'Etudes Spatiales (CNES, France).

The committee is chaired, in turns. by CNES and NOAA. The Operations Committee is responsible for ensuring that the system is run according to the 'Memorandum of Understanding", a France-American agreement signed on December 10, 1979.

Argos programs
A program is defined as a user-specific application of the Argos system.

Conditions for program acceptance
The Argos system is strictly reserved for programs for the collection of environmental data, defined as measurements of physical, chemical or biological properties of solid earth, earth's waters (rivers, lakes and oceans) and the atmosphere (including space). Applications not directly concerned with the environment may, in exceptional cases, be' approved by the Operations Committe provided that the program lasts no more than six months.

7.1 APPLICATION PROCEDURE

The three stages of the procedure are :
- application;
- technical preparation;
- signing of contract.

Each stage gives nse to an exchange of documents between Service Argos and the user.

APPLICATION

The prospective user fills out a questionnaire called the "Program Application form", a facsimile of which is enclosed with this Guide. The information to be supplied is as follows :
- particulars of the applicant, the "program director";
- description of the aims of the program,
- program time frame (starting date, duration),
- PTT characteristics (number, type),
- brief definition of any processing operations to be performed by Service Argos.

The application may be in either English or French.
The average time for a reply to be given is one month. If the application is approved, Service Argos sends the user the documents listed below. These documents must be returned to Service Argos before any PTTs start transmitting
- "Program review", giving the assigned PTT ID (identification) numbers and repetition periods;
- "technical file", a detailed technical questionnaire stating in precise terms the user's processing and access requirements;
- Service Argos tariff and a purchase order.

It is up to the user to make any necessary arrangements with local or national authorities to obtain licenses for PTT operation.
If the Operations Committee decides to refuse the program, a special letter is sent and the reasons for the refusal stated

Approval priorities
Applications are treated in accordance with the following priorities, in particular when there is a risk of saturation of the system
First priority programs requiring the unique capabilities of the Argos system and which are devoted to environmental monitoring.
Second priority programs devoted to environmental monitoring but which may not require the unique capabilities of the Argos system, for example programs which could be handled by geostationary satellite systems.
Third priority: programs not related to the environment but which satisfy the above conditions.

TECHNICAL PREPARATION

The use of new PTTs necessarily involves an exchange of technical information between Service Argos and the user.

Program review
As soon as an application is approved, Service Argos begins a thorough examination of the information supplied As a result of calculations based on the number of PTTs already set up in the area concerned, Service Argos can determine the new number of messages that will be received each second by the satellite.
The aim is to determine whether there will be any adverse effects on system performance..
The results of the study (compatibility considerations, repetition periods. ID numbers) will be given in the "Program Review" document.

Technical file
By filling out this document. the user provides Service Argos with all necessary reformation relating to his program needs, that is
- sensor data processing options:
- location needs:
- on-line data dissemination options;
- off-line data dissemination options.

7.2 CONTRACTS

Service Argos is operated on a cost-recovery basis, with users contributing a fraction of the running costs proportional to the amount of service required. Government users from the same country can reduce their financial contribution by jointly signing a "Global Contract", Services not covered by a Global Contract are ordered from Service Argos by each user separately.

TYPES OF SERVICE

The following services are available for approved programs (see also figure 7.2.A):

Type 1: Standard service for PTTs with a repetition period of less than 60 seconds. Service Argos performs PTT location calculations, sensor data processing, generation of accessible data files and archiving of results for three months.

Type 2: Standard service for PTTs with a repetition period greater than 100 seconds. With the exception of location calculations, which cannot be achieved with such PTTs, Service Argos performs the same tasks as in type 1, i.e. sensor data processing, generation of accessible output files and archiving of the output data for three months.

Type 3: Back-up service for PTTs with a repetition period of less than 60 seconds. Acquisition of data from these PTTs must, in general, be via the user's own direct readout station. The processing of these data is the same as in type 1, except that results are not supplied. Results are, however, archived for a period of three months, during which time the user may request them. The required period must not exceed three months, counting back from the date of the request, and it must cover a whole number of calendar months. For billing purposes, the PTTs concerned are considered as having been processed under type 1, over the period requested.

Type 4: Back-up service for PTTs with a repetition period greater than 100 seconds. Same as type 3, except that there is no location calculation.

Type 5: Monitoring service for PTTs with a repetition period of less than 60 seconds. These data must generally be acquired via the user's own direct readout station. Service Argos performs the same processing operations as in type 1, the aim being to monitor system use by this category of PTT. Results are not supplied to users, not archived, and therefore are not accessible.

Type 6: Monitoring service for PTTs with a repetition period greater than 100 seconds. Same processing as type 5.

Figure 7.2.A
SERVICES AVAILABLE UNDER THE GLOBAL CONTRACT

SERVICE	STANDARD		BACK-UP		MONITORING	
	1	2	3	4	5	6
Repetition Period	<60S	> loos	<60S	> loos	<60S	> loos
Location	Yes	No	Yes	No	Yes	No
Data Processing	Yes	Yes	Yes	Yes	Yes	Yes
Access to Data Files	Yes	Yes	No	No	No	No
Data Archiving	Yes	Yes	Yes	Yes	No	No

The basic accounting unit used by Service Argos is the "PTT-day", defined as one day of PTT data processing, with a maximum of six locations or ten data collections during the day.

GLOBAL AGREEMENT

The Argos Global Agreement is prepared every year at a meeting convened by tha World Meteorological Organization. Individual agreements are concluded between Service Argos and countries concerned, The agreement involves the payment of a fixed reduced cast covering all PTT usage up to a certain global maximum. All countries are encouraged to join the Global Agreement and enjoy preferential tariff arrangements, Notice must be given in time to conclude an agreement with Service Argos before March 1 of each year, Each country interested in joining the Global Agreement must designate a national co-ordinator, named the "Representative Organization for the Country" (ROC). The main tasks of the ROC in relation to Service Argos are:

- to supply, and update as necessary a list of programs covered by the contract; programs authorized m the context of the Global Contract are limited to those funded entirely by non-profit-makmg institutions such as government agencies:
- to negotiate with Service Argos the minumum guaranteed system use for programs covered by the Contract, and to pay for 12 months service in advance.

Each program authorized under this agreement must also comply with the general rules governing system use. The standard application form must therefore be completed and sent to Service Argos where it will be reviewed in standard manner.

The accounting unit used m connection with a Global Contract is the Type-1 "PTT-day" A PTT that does not in fact use type 1 processing only gives nse to a fraction of a PTT-day. The fractions are given below.

Type	1	2	3	4	5	6
Fraction	1	1/5	1/5	1/15	1/8	1/16

Users operating programs under a Global Contract will be charged in accordance with the Service Argos tariff for any services not included in the Contract, Program heats order such services by signing, completing and sending a Service Argos purchase order once a year

PROGRAMS NOT COVERED BY A GLOBAL CONTRACT

User programs not covered by a Global Contract, for example those from non-participating countries or those operated by commercial organizations. must order services directly from Service Argos. Contributions to operating expenses are specified in the Service Argos tariff (enclosed with this Guide)

INDEX

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LIST OF ACRONYMS

ATN	Advanced TIROS-N
BCD	Binary coded decimal
CDA	Command and Data Acquisition
CMS	Centre de Meteorologic Spatiale
CNES	Centre National d'Etudes Spatiales (French Space Agency)
DCLS	Data Collection and Location System
DCP	Data Collection Platform
DMN	Direction de la Meteorologic Nationale
ESM	Equipment Support Module
EURONET	European data transmission network
F G G E	First Global GARP experiment
GARP	Global Atmospheric Research Program
GOES	Geostationary Environmental Satellite
GTS	Global Telecommunications System
HRPT	High Resolution Picture Transmission
ID	Identification number
IGC	International Gateway Center
IMP	Instrument Mounting Platform,
LUT	Local User Terminal
METEOSAT	Meteorological Satellite (European)
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite and Data Information Service
NF	Compression index
NOAA	National Oceanographic and Atmospheric Administration
NQ	Index of message quality
OC	Operations Committee
PTT	Platform Transmitter Terminal
ROC	Representative Organization for a country or a group of countries
RTH	Regional Telecommunications Hub
RSS	Reaction Support Structure
TELENET	North American data transmission network
TIP	TIROS Information Processor
TRANSPAC	French data transmission network
TYMNET	North American data transmission network
UTC	Universal Time Code
VHF	Very High Frequency
WMO	World Meteorological Organization
WWC	World Weather Center
WWW	World Weather Watch

Contract #14-12-0001-29169

CUTANEOUS RESPONSE m PLASTIC AND METALLIC IMPLANTS

OF POTENTIAL USE FOR MARKING CETACEANS

FINAL REPORT

PART II

Prepared for:

U.S. Department of the Interior
Minerals Management Service
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To assess the potential value of percutaneous implants to mark free-ranging cetaceans, we examined the cellular response to metallic and plastic substances implanted in the dorsal fins of dolphins. Of the nine materials tested, eight were extruded within three weeks; only one (high density polyethylene) was retained for the 12-week study period. Histological examination of the polyethylene implant revealed that this material had not been completely accepted. The findings indicate the need to develop a composite implant, which allows ingrowth of fibrous tissue, yet forms an effective barrier to penetration by micro-organisms.

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PERCUTANEOUS IMPLANTS

EXECUTIVE SUMMARY

We sought to characterize the cutaneous response in bottlenose dolphins, Tursiops truncatus, to Materials of potential value in future marking programs on cetaceans. Our first step was to determine the inflammatory response and the rate and pattern of wound healing in dolphin skin. The sequence and timing of healing were similar to those reported in terrestrial mammals. Of note was the absence of a traditional scab, its purpose served by a transformed barrier layer of epidermal cells and vesicles.

We then implanted Plastic and metallic substances percutaneously into the dermis of the dorsal fins of three dolphins. There were three responses. Eight materials were extruded by the third week, followed by normal healing in seven and infection in one. The only material remained over the 12-week study period was porous polyethylene. anchored firmly by an ingrowth of fibrous tissue. Zones of reactivity remained around the implant. indicating that the material had not been completely accepted. We believe that the results are promising, and the impediment to total acceptance can be overcome by constructing a composite implant with a surface which is impervious to penetrating substances, a collar which forms a firm epidermal seal, and a base with suitable porosity to allow rapid invasion by fibrous tissue.

INTRODUCTION

Identification of individual cetaceans *is* essential to understanding behavior, abundance, distribution and movements. Such identification can be achieved through the use of natural and artificial marks, visible tags, and radio transmitters.

Efforts to identify individual whales began in 1932 with the development of "Discovery" tags fired from a shotgun into the flesh of large whales and recovered during processing after the animal had been killed. By 1975 over 20,000 whales were marked. with recovery rates approaching 15% (Brown 1977). In the 1960's. investigators began experimenting with tagging methods which could be used with small cetaceans and did not require killing the animal. After some abortive attempts (Nishiwaki et al. 1966), Sergeant and Brodie (1969) successfully marked *Delphinapterus leucas* using spaghetti tags. The recovery/refighting rate however, was only 0.4%. Since then, a variety of tags and marking techniques have been developed and tested. The five basic methods include natural marks (Katona et al. 1979, Perkins and Whitehead 1977, Würsig and Würsig 1977, and Schevill and Backus 1960), freeze branding (Cornell et al. 1979, Irvine and Wells 1972), button or disk tags fastened through the dorsal fin (Evans et al. 1972). dart-type spaghetti tags (Evans et al. op. cit., Perrin et al. 1979) and radio transmitters (Leatherwood and Evans 1979, Mate and Harvey 1983). Despite increasingly sophisticated designs and application techniques, none of the devices are dependable enough to be used routinely. They are either too

difficult to apply, rejected, cause inordinate tissue damage, or fail because the materials are not durable or the marks distinctive (White et al. 1981, Hobbs and Goebel 1982, Irvine et al. 1982). Of the various tags, radio transmitters show the greatest promise for providing long-term information. Their usefulness however. depends on the duration of attachment to the animal. In small cetaceans, a radio tag can be manually fastened to a specific site on the dorsal fin. In larger whales, tags must be implanted remotely, usually from a shoulder gun. In either case. but particularly the latter less controllable method, tissue reaction, infection, and hydrodynamic drag loosen, displace, and eventually cause the loss of the tag. Results of some recent disappointing whale tracking studies led to the conclusion that "without knowledge of the dynamics of the tissue reactions, we may never have a long-term tag . . .." (Watkins 1981).

Toward this end, we undertook the present study in three phases. First, we characterized the inflammatory response and the rate of wound healing of surface cuts made in the skin of *Tursiops truncatus*. Using the same subjects, we then conducted a pilot study to determine the response of skin to stainless steel and gold-plated pins inserted to the full depth of the dermis. Despite the strenuous effort needed to implant the devices, three of the four pins were rejected within three days, and the fourth by day nine (Geraci and St. Aubin, 1984). That finding clearly pointed to the need for a study to determine the nature of the processes leading to acceptance or rejection of percutaneous implants.

The present study addresses the question by examining, in the bottlenose dolphin, the reaction of skin to a series of materials selected on the basis of composition and configuration. and some because of their success as implants in human surgery. These included: 120-HOPE, Proplast 11, urethane, and titanium. Others were tested because they are highly resistant to seawater (i.e. copel, inconel, and monel). For comparison with these inert materials, we tested a type of stainless steel that is resistant to corrosion by body fluids but not seawater, and copper which is quite reactive and non-resistant.

As a background to these studies, we have provided a description of epidermal structure in the bottlenose dolphin. This account, along with a glossary of terminology, will facilitate interpretation of the histological descriptions which fol low.

EPIOERMAL MORPHOLOGY IN *TURSIOPS TRUNCATUS*

Odontocete skin has a smooth rubbery texture. It is without glands or hair. except for the few curly bristle-like sinus hairs along the snout of fetuses. The epidermis is 10 to 20 times thicker than that in terrestrial mammals, measuring 2 to 4 mm in *Tursiops*. The thickness is variable over the surface of an animal, and changes with age (Harrison and Thurley 1974). The deeper half of the epidermis is penetrated by erect evenly spaced dermal ridges aligned parallel, obliquely, and to a lesser extent, perpendicular to the long axis of the body and fins. From the summmits of the dermal ridges arise finger-like dermal

papillae (Fig. 1). Nerve fibers from these well-innervated. vascularized papillae penetrate the epidermis only in the teat, genital and anal regions (Palmer and Weddell 1964).

There is disagreement over the number of cellular strata present in the epidermis. We recognize three layers. The first which rests on the basement membrane overlying the dermis has been called stratum basale or stratum germinativum. Both names aPPear to be interchangeable but the latter term best describes its function, which is to proliferate and produce the overlying epidermal cells. Melanocytes are interspersed among the germinal cells. Above the germinal layers lie 35 to 50 rows of cells which are spherical near their origin on the stratum germinate - vum, and become flattened "and eliptical toward the surface of the skin. This we refer to as the stratum spinosum.

Some controversy surrounds the precise nature of the external layer. Authors noting that it is keratinized have adopted the name stratum corneum. Although some keratin can be demonstrated histochemically, most would agree that the process of cornification is incomplete. hence we prefer Harrison and Thurley's (1974) designation of stratum externum.

It has been suggested that the cells of the stratum externum are still living (Simpson and Gardner 1972). However, the nuclei are condensed and pyknotic, and the cytoplasmic organelles are sparse, suggesting that the cells are senescent. Cells at the surface exfoliate intact.. They can be scraped off easily and sheets of epidermis are often found in pools where small odonto-Cetes are maintained.

WOUND HEALING[1]

MATERIALS AND METHODS

Three. 4-year-old. female bottlenose dolphins, *Tursiops truncatus*, were captured in Mississippi Sound and maintained in sea-pen enclosures at the Institute for Delphinid Research, Grassy Key, FL for 16 months prior to the study. ' Each dolphin was fed herring. *Clupea harengus*, and smelt, *Osmerus mordax*, providing a daily ration of 3.4 x 105 $J \cdot kg^{-1}$ body weight/day. During the study period. the animals were in good health, judging from appetite. general appearance, and results of hematologic and serum chemical analyses.

For each trial the dolphins were netted, placed on a standard dolphin transport stretcher, and suspended side-by-side just above the surface of the water in a metal carrier frame. The animals were restrained and kept wet for up to 3 hours. Following each session the dolphins were fed as soon as they were returned to the holding pool.

We examined the healing process by making two 10-cm long superficial cuts on the back of each animal. A sterilized No. 11 scalpel blade, wrapped with masking tape so that 2 mm of the tip was exposed, was drawn quickly through the skin. A paper ruler, placed cranial and at right angles to the dorsal fin, was used to

[1]These observations form part of a forthcoming publication (Bruce-Allen and Geraci 1985).

guide the blade. Bleeding was controlled within 1 minute using a gauze sponge, after which each cut was infused with sterile seawater for 30 minutes.

The cuts were photographed and elliptical skin biopsy specimens were excised in duplicate at 2, 6, 12 hours, and 1, 2, 3, 7 and 10 days after each cut was made. They were removed serially beginning at one end of the incision. Each specimen exposed the dermis and incorporated the opposing edges of the wound and normal surrounding tissue.

Samples were immediately placed in 4 mL of 3% glutaraldehyde in 10% buffered formal in (0.2 M sodium phosphate buffer. PH 7.0). at 40C for up to 1 hour. Each specimen was then bisected longitudinally. One half was placed in 4 mL fresh glutaraldehyde-formalin fixative for light microscopy, and the other was diced into 1-mm^3 pieces and placed in 4 mL of the same fixative for electron microscopy.

Tissues fixed for light microscopy were dehydrated in alcohol, and embedded in paraffin blocks. Sections 10 to 12 μm thick were stained with hematoxylin and eosin (H&E). Selected subsamples from each time interval were stained with periodic acid schiff (PAS). phosphotungstic acid hematoxylin (PTAH), and Masson's trichrome.

For electron microscopy, specimens were post-fixed in 1% osmium tetroxide in 0.2 M sodium phosphate buffer for 1 hour at 4°C. They were then washed in 0.2 M sodium phosphate buffer, dehydrated in acetone, and embedded in Spurr's medium. Thick sections (1 μm) were cut on glass knives using a Reichert OmU2 ultramicrotome (Sargent-Welch Scientific of Canada Ltd., Weston, Ont.) and stained with 1% methylene blue in 1% sodium borate solution at 90^{o}C for 1 minute. Thin sections (150 μm) were placed in 200 mesh copper/nickel grids and stained with 2% uranyl acetate in water for 20 minutes, and lead citrate for 5 minutes. Thin sections were viewed on an Hitachi HS-9 (Nissei Sangyo Canada Ltd., Rexdale, Ont.) electron microscope.

Inflammatory cells located at the base of the incision were identified in H&E stained sections as neutrophils, eosinophi s, or mononuclear cells using oil immersion (1000x). Each of the three cell types was counted in six random 2.0×10^{-3} mm^2 fields on three histological sections using a gridded ocular. The mean and standard deviation of the six counts were calculated to yield a value for the density of each inflammatory cell type. Mitotic activity was determined by counting 500 germinatival cells within 2 mm of the incision ne, and determining the percentage in metaphase.

RESULTS

Gauze pads were immediately applied to the cuts to minimize bleeding, which stopped within 2 to 3 minutes. Bleeding could be induced again by gently massaging the cut during the next 2 hours but not thereafter.

2 Hours

Incisions after 30 minutes and 2 hours showed sharp clean edges separated by a space approximately 2 mm wide (Fig. 2B). After 2 hours the incisions were filled with coagulated

blood. Histologically, the clot was composed of erythrocytes and strands of fibrin. Epidermal cells from the margins of the incision inward to a depth of up to 0.2 mm at the base and 1.0 mm at the surface were pale, had pyknotic nuclei, and lacked distinct cel architecture (Fig. 2C). At the base of the incisions, mild intercellular edema was evident in the stratum germinativum and the first few layers of the stratum spinosum. Small blood vessels in the peri-incisional dermis were dilated and congested (Fig. 2D). The endothelial cells were fusiform and contained numerous peripheral vesicles. Erythrocytes and a few neutrophils were commonly observed adhering to the walls of the vessels. Neutrophils were identified as round to ovoid cells, 5-10 μm in diameter, containing polysegmented nuclei and two species of cytoplasmic granules. The cells often possessed cytoplasmic extensions devoid of organelles.

DISCUSSION

Wound healing in the bottlenose dolphin does not differ dramatically from that reported in terrestrial mammals. Indeed, the sequence of vascular and cellular events corresponds with those reported in rats (Hurley et al. 1966), mice (Croft and Tarin 1970), guinea pigs (Ross and Benditt 1961), rabbits (Matoltsy and Viziam 1970), and man (Ross and Odland 1968).

Healing of *cutaneous* incisions in dolphins, as in all animals with a vascularized blood system, involves immediate changes in local blood flow which culminate in the infiltration of inflammatory cells into the damaged area. Vascular dilation, congestion, and hemorrhage at 2 hours were followed by rounding, or contraction of endothelial cells, extravasation of leukocytes, and edema. Neutrophils predominated inflammatory infiltrates throughout the course of healing. Phagocytosis appears to be a key function of these cells in the dolphin, as evidenced by the development of intracellular phagosomes which fuse with cytoplasmic granules. The life span of neutrophils in the wound area was relatively short, only 6 to 12 hours. However, the release of cellular contents and enzymes from necrotic neutrophils early in the response probably continues to contribute to inflammation as it does in other mammals, effecting increased vascular permeability (Juhlin and Hammarstrom 1982), degradation of immune complexes bound on nonphagocytosable surfaces (Henson 1980) and chemotaxis of inflammatory cells (Goetzl and Pickett 1980).

Mononuclear cells appeared in inflammatory infiltrates more frequently subsequent to the peak emigration of neutrophils.

This finding supports Ryan's (1967) belief that emigration of inflammatory cells is a biphasic process. The dolphin macrophage is the principal phagocytic inflammatory cell seen to ingest large particles and cellular debris. Lymphocytes were identified infrequently in the cuts and did not share a phagocytic role with macrophages and neutrophils.

Eosinophils were regularly encountered in the cellular infiltrates. Ultrastructurally, cetacean eosinophils differ from those of most terrestrial species in that the granules lack crystalloid. This may signal an evolutionary modification of antigenic properties of the cells (Kay 1979), and it is therefore interesting to note that the lack of a crystalloid is a feature also seen in equine eosinophils. Epidermal cuts in the dolphins were not characterized by a large infiltration of eosinophils, despite high levels in circulation (Medway and Geraci 1978). The phagocytic capabilities of these cells were clearly evident in cellular infiltrates. However, their low occurrence suggests that they do not play an important role in response to mechanical injury.

Concurrent with infiltration of inflammatory cells and wound debridement were changes in the morphology and function of local epidermal cells. The first sign of epidermal involvement in healing was migration of cells using stationary epidermal cells, fibrin, and mesenchymal cells in the dermis as a substrate. Our results support the interpretations of Krawczyk (1977) that epidermal migration is accomplished by the sequential movement of individual cells in a "leap-frog" motion. The retention of few desmosomes between migrating and stationary epidermal cells may permit increased mobility of the cells, while interdigitation of plasma membranes would maintain contact between cells and may provide directional information to the migrating cells.

Elevated mitotic rate of basal epidermal cells also contributed to the reestablishment of normal tissue. The period of increased mitotic activity in the dolphin is within the range reported for non-occluded wounds in man (Rovee et al. 1972). Clusters of cells in metaphase were first observed at 48 hours, subsequent to the coaption of migrating epidermal cells beneath the cuts. Increased mitotic activity and cellular migration may well have been concurrent processes. However, the peak of mitotic activity was noted only after a continuous germinal layer was established.

Increased mitotic activity is concentrated in the stratum germinativum and overlying few layers within 1 mm of either side of the incisions. The zone of stimulated mitosis is far more restricted than that reported in terrestrial mammals (Silver 1982). To account for the difference, one must consider the microanatomy of normal cetacean skin. The very pronounced dermal papillae provide a large surface area for the stratum germinativum. Consequently, a dolphin has more germinal cells in the immediate area of a given wound, and thus, it seems, can produce the cells required to fill an incisional gap from within a very short distance of the injury;

Anderson and Roberts (1975) suggested that rapid wound closure in fish is an important adaptation to an aquatic

environment. Likewise, it has been stated that wound healing in cetaceans proceeds at a remarkably fast rate (Greenwood et al. 1974). The present study does not substantiate this claim. Instead, the current findings place the temporal sequence of wound healing in the dolphin within the reported time frame observed for man (Ross and Odland 1968) and rabbits (Matoltsy and Viziam 1970). This time frame will be used as a basis upon which to compare wound healing associated with implantation marking and tracking devices.

PERCUTANEOUS IMPLANTS

MATERIALS AND METHODS

Three female bottlenose dolphins (*Tursiops truncatus*) were used in this study. They were maintained at the New England Aquarium, Boston, in a 6.7 m x 13.7 m x 1.8 m deep pool containing chlorinated (<0.05 ppm free chlorine) seawater at a temperature of 17–18°C, salinity of 32‰ and a pH of 8.0. The dolphins were designated "ELM-A", "BLM-B", and "Elua". ELM-A and BLM-B were both six years old and had been in captivity for nearly four years. Elua was approximately 19 years old and had been in captivity for 15 years. All were in good health, as judged by physical condition and blood analyses. The dolphins were fed a diet of thawed herring (*Clupea harengus*) and capelin (*Mallotus villosus*) providing 1.4 to 2.4 x 10^5 $J \cdot kg^{-1}$ of body weight per day.

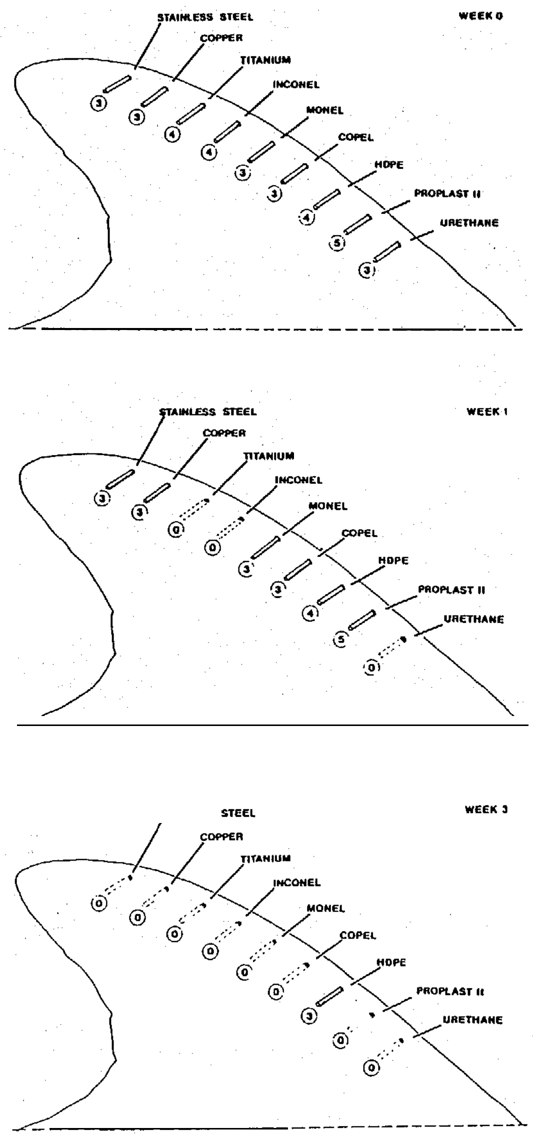
To implant the materials, each dolphin was captured, restrained in a standard dolphin transport stretcher, and placed on a foam pad at pools ide, where it was kept moist by sponging during the 30 minutes required to complete the procedure.

Nine different materials were implanted (Table 2), in the form of small rods 20 mm long and approximately 1.6 mm in diameter. The Prop last 11. 120-HOPE, and urethane implants were placed in a steam sterilizer for 20 minutes, then stored dry in sealed containers: the metals were cleaned in 100% acetone, stored in 100% ethyl alcohol. then rinsed in a sterile 0.9% saline solution. To insert them. a 14 gauge needle was used to make channels through the dorsal fin, 1 cm from the leading edge and 2 cm apart. One implant was inserted to the ful 1 depth of each channel flush with both surfaces of the fin. Control channels, without implants, were also made in each dorsal fin. The distribution of implants and control sites is shown in Fig. 10.

One implant site for each material. including a control from each dolphin, was sampled using a 6-mm diameter biopsy punch at 1, 3. and 6 weeks following implantation. Additional biopsy samples of Proplast 11, 120-HOPE, inconeland titanium sites were removed after 12 weeks. A total of 37 samples were obtained during the 12-week study period. At each biopsy session. all sites were examined and photographed. Biopsy specimens were placed in universal fixative for 72 hours, then dehydrated in a graded series of ethyl alcohol. infiltrated with methacrylate for 7 days and embedded in methacrylate in a vacuum desiccator. Sections were cut at 2-5 μm and stained with hematoxylin and eosin.

Table 2: Materials implanted percutaneously in three bottlenose dolphins, _Tursiops truncatus_.

MATERIAL	DESCRIPTION	SUPPLIER	DOLPHIN
120-HOPE	porous high density polyethylene pore size: 120 μm porosity: 40,% tensile strength: <4.8 MPa modulus of elasticity: 210 MPa	Porex Technologies Fairburn, GA	owl-e
Proplast 11	porous composite of polytetrafluoroethylene combined with aluminum oxide pore size: 100-400 μm porosity: 70-90% tensile strength: 0.03-1.0 MPa modulus of elasticity: 2.2S MPa	Vitek, Inc. Houston, TX	em-e
Urethane	pol yether urethane tensile strength: 31 MPa modulus of elasticity: 1.6 MPa	BrandoFlex, Ltd. Brant ford, Ont.	BLM-A
Copper	99% pure Cu	Lewis Tool & Oie Ltd. Guelph, Ont.	BLM-A
Titanium	99.7% pure Ti	Johnson Matthey, Inc. Seabrook, NH	Elua
Copel	copper-nickel alloy consisting of 55% Cu and 45% Ni	Lewis Tool & Oie Ltd. Guelph, Ont,	BLM-A
Inconel 671	nickel-chromium alloy consisting of 52% Ni and 48$ Cr	Lewis Tool & Oie Ltd. Guelph, Ont.	BLM-B
Monel 400	nickel -copper alloy consisting of 66.5% Ni, 31.5% Cu, and 2% Co	Lewis Tool & Oie Ltd. Guelph, Ont.	Elua
416 Stainless Steel	a member of the martensitic group of stainless steels	Lewis Teal & Oie Ltd. Guelph, Ont.	BLM-A



Each section was examined histologically for local cellular response, and the extent and type of tissue ingrowth in the two porous plastic materials. A total of 668 sections were examined. Five sections from biopsy samples of the 120-HDPE implant sites taken at weeks 1, 3, 6, and 12, and five sections from biopsy samples of control sites taken at weeks 1, 3, and 6 were examined for the presence of mitotic figures. Mitotic figures were classified as late prophase, metaphase-anaphase, or telophase. The mitotic index (number of mitotic figures/1000 basal cells) was calculated for individual dermal papillae, as well as for each biopsy sample overall.

RESULTS

All three dolphins quickly resumed normal behavior and feeding patterns following the implant procedure, and remained healthy during the 12-week study period as judged by appetite, general appearance, and results of hematologic and blood chemical analyses. Except for the presence of implants, the dorsal fins remained normal in appearance throughout the study (Fig. 11), and the dolphins did not exhibit any behavior suggesting physical distress.

Histological examination of the implant sites revealed three types of tissue response. These were (1) extrusion of implants followed by normal wound healing; (2) extrusion of implants with abscessation, ulceration, and delayed wound healing; and (3) some degree of tissue ingrowth into the implant material (Fig. 13). In category one, inconel, titanium, and urethane were extruded

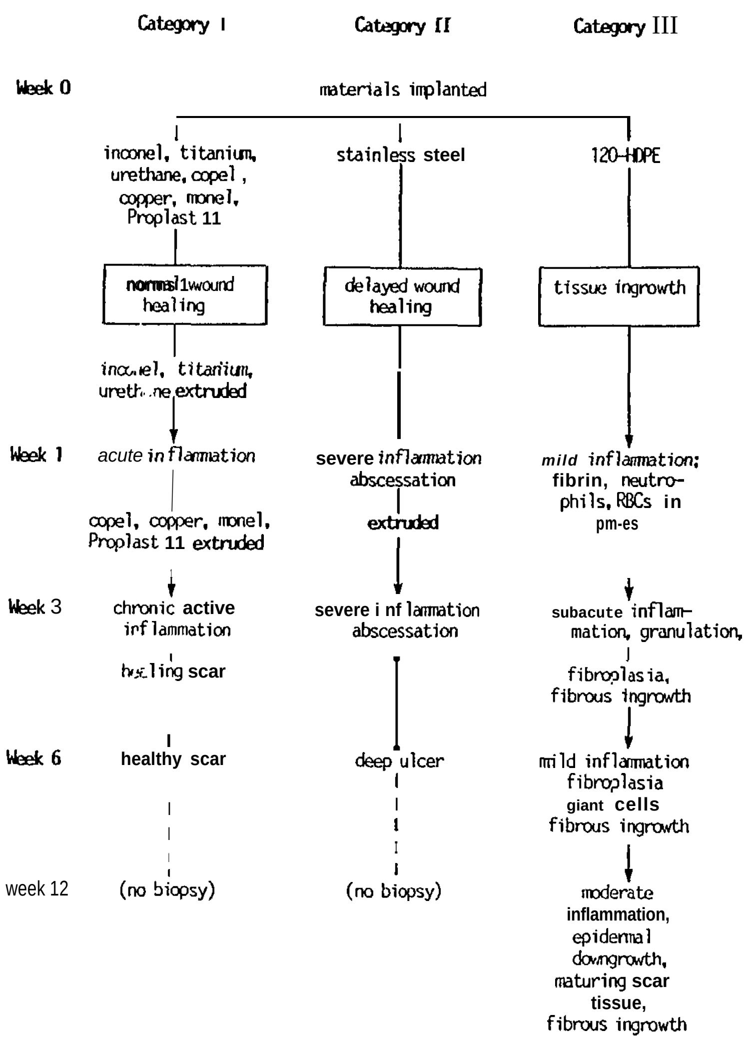


Figure 13: Tissue response to nine different materials implanted percutaneously in dorsal fins of bottlenose dolphins.

within one week; copel, copper, monel, and Proplast II were extruded before three weeks. Stainless steel was the only material tested that fell in the second category; all implants were extruded by the third week. The single material in the third category, 120-HOPE. remained implanted throughout the study.

1. CONTROLS

<u>Gross Description</u> (Fig. 14)

After one week, all nine control sites appeared similar. The center of each site contained a slightly raised dark scab approximately 3 mm in diameter which was surrounded by a narrow pale halo. By week 3, the remaining six control sites had a slightly depressed pin-point black center surrounded by normal skin. The three control sites, which had been biopsied two weeks previously, appeared as dark, slightly depressed scabs approximately 6 mm across. By week 6 only one of the three remaining control sites was readily distinguishable from the surrounding tissue. It was visible as a pale l-mm dot surrounded by a 4-mm halo of dark, relatively normal-appearing skin.

<u>Histological Description</u>

Week 1 (Fig. 15) - Epidermis - The stratum externum was continuous across the wound site. and was thickened due to hypertrophy and hyperplasia of some of the cells. A mild neutrophilic infiltrate percolated up between the layers of the stratum externum. The stratum spinosum was only a few cell layers thick at

thickness of the normal epidermis. Rete pegs more distant from the implant were not affected. The basal cells of the epidermis adjacent to the i replant had 1 arge nuclei. prominent chromatin patterns and large nucleoli. The underlying basement membrane was thickened. Mitotic figures were present in the germinal cell layer up to five rete pegs away from the implant (1.2.5 ± 8 cells·1000^{-1}), but were most numerous in the peg immediately adjacent to the implant (22 ± 8 cells. 1000^{-1}, Table 3). The mild inflammatory cell infiltrate in this region consisted primarily of neutrophi 1s.

Dermis - The pores of the implant within the dermis were filled with fibrin. erythrocytes, neutrophi ls, . cellular debris, macrophages, and giant cells. Maturing fibrous tissue penetrated pores along the periphery. The dermal reaction was confined to the area immediately adjacent to the implant, and consisted of maturing scar tissue, and a mixed inflammatory cell infiltrate containing neutrophi 1s, macrophages, and a few giant cel ls.

DISCUSSION

This study was designed to investigate the nature of the response of dolphin skin to percutaneous implants, and to determine how it is influenced by physical and chemical characteristics of the implanted material. We observed three different reactions: extrusion by week 3, followed by normal. uncomplicated wound heal ing; extrusion by week 3, associated with abscessation and finally ulceration by week 6; and retention until at least week 12 with moderate tissue ingrowth.

Any sol id material penetrating the epidermis initiates a series of cellular processes designed to isolate and expel the intruding substance before the heal i ng process can be completed. The mechanisms involved in rejecting percutaneous y implanted materials have been reviewed by von Recum (1984). These include marsupial ization, permigration, infection and avulsion. Marsupialization refers to the proliferation of epidermal cells along the interface between the tissue and the i replant (epidermal downgrowth). Once the leading epidermal edges join under the implant, the body has successful 1 y externalized the material. Permigration occurs with porous implant materials. which are infiltrated first by connective tissue, then by epidermal basal cells. There is some controversy concerning the mechanisms leading to rejection of porous materials. Hall et al. (1975) postulated that the natural tendency for epidermal cel 1s to" migrate towards the surface of the skin creates a force which carries the implant outward. Von Recum (1984) found that basal cel 1s were able to penetrate the i replant to reach healthy granulation tissue resulting in marsupial ization. If the implant material is contaminated, infection results in rapid destruction of tissue surrounding the implant and subsequent extrusion. Mechanical forces acti ngon percutaneous devices are transmitted to interracial tissues where the stresses lead to focal acute inflammation. If the forces are great enough, the i mpl ant may be torn away from surrounding tissues. Mechanical l y induced f ailure has been termed avulsion (Daly 1980). Von Recum (1984) believes that failure is usually due to a combination of these factors which lead to sinus tract formation, mechanical disruption of weak tissue bridges, infection and ultimately extrusion.

In our study. some of the implant materials were lost during the first week, and others within three weeks. Histologically, we could find 1 ittle difference between these two groups suggesting that the implants in the second group were lost early during the second week.

Al 1 substances in this category caused marked inflammation, followed by fibroplasia and formation of maturing scar tissue. The sequence of events paralleled that observed in uncomplicated wounds (see Wound Heal ing section, this report) but the time course was extended due to the presence of implant material. Extrusion was apparently the result of infection and avulsion.

The early loss of titanium was unexpected; it has been used extensively in prosthetic devices, has exceptional ly high corrosion resistance, and usually produces little tissue response (Williams 1981). Inconel, monel, and copel are al 1 metal alloys exhibiting similarity high resistance to corrosion by seawater and alkal ine media (American Society for Metals 1980), yet they too were rapidly rejected. Chemical unreactivity, therefore, is not the sole criterion for the selection of material for percutaneous implantation in dolphins.

Early extrusion of the Proplast 11 implants was particularly intriguing since stabilization of porous implants by ingrowth of surrounding tissue has been found desirable for long-term clinical stability (Homsy 1981). Extensive information in the literature indicates that Proplast II should be accepted since it meets three key needs: biocompatibility, because the ingredients (PTFE and alumina) are stable in the body; biofunctionality, with a modulus of elasticity similar to that of soft tissue (3 M Pa) which should prevent shearing of ingrown tissue buds under mechanical stress: and porosity, because the pore size (100-400 urn). pore volume (70-90% void), and interpore connections (>100 µm) are optimum for active tissue metabolism and maturation (Westfal 1 et al. 1982, Homsy and Anderson 1976).

The reasons for extrusion of the Proplast I I implants are not clear, but the manufacturer has suggested two possibi 1 i ties (R. Tal ly pers. comm.). Compression during trimming prior to implantation or d:ring the implant procedure may have col lapsed the pores. inhibiting ingrowth, or the implants may have been subjected to mechanical stresses which destroyed weak interracial tissue bridges as quickly as they developed. The low modulus of elasticity makes Proplast susceptible to deformation during handling. Percutaneous devices, no matter how carefully implanted, are subject to i.:'ection (Dasse 1984). Infection may result from an initial superficial colonization adjacent to the implant, or a sinus tract may develop around the implant allowing bacteria access to subcutaneous tissue. Chronic infection, which may not be counteracted successful ly due to pressure necrosis or excessive *tissue reaction* to *toxic* biomaterials, progresses to abscess formation. Apparently this was the case with the stainless steel implants. After one week a narrow sinus tract led from the skin surface to a pocket of necrotic debris in the dermis. There was no sign of bacterial infection at two weeks, but a large ulcer was present at six weeks.

It would appear that the sinus tract provided a tunnel for deep infection, resulting in abscessation. The consequence was extrusion of the implant due to tissue breakdown in the dermis and the development of a sinus tract in the epidermi lined with differentiated stratum externum.

The only implant material still in place after 12 weeks was porous polyethylene 120-HOPE. Polyethylene has a long history of clinical appl i cation, especial ly in total joint prostheses, yet there have been few experiments with porous polyethylene (Hastings 1981). Klawitter et al. (1976) found well developed ingrowth with few inflammatory cells in porous samples implanted in dog femora. Similar results were obtained with a porous polyethylene total ossicular replacement prosthesis in humans (Smyth et al. 1978). We are unaware of any trials using porous HOPE as a percutaneous implant.

Of significance in the present study was the rapid onset of fibroplasia adjacent to the implant, coupled with only a mild inflammatory response during the first week. 8y week 3 there was some growth of fibrous tissue within the pores of the implant, and by week 12 the fibrous tissue was maturing. This reaction was markedly different from that observed with the other porous material investigated in this study. Before the end of the first week, the pores of the Proplast II implant had fi1 led with an inflammatory exudate, and acute inflammation was present in the dermis. By week 3, al l of the Proplast II implants had been extruded and we were unable to find any histological evidence indicating that infiltration by fibrous tissue had commenced. We conclude that a major requirement for successful percutaneous implantation in dolphins is a material that allows rapid formation of fibrous tissue within its pores to quickly create a physics l bond between the material and surrounding tissue.

We examined mitotic activity to obtain a quantitative measurement of tissue response to the 120-HDPE implants. The rate of mitotic activity associated with the 120-HDPE implant sites was similar to the control site values in weeks 1 and 3. but decreased drama tically by week 6 (Fig. 30) to normal values for untraumatized skin (see Wound Healing section, this report). Although the rate observed in the biopsy sample obtained on week 12 had increased somewhat. it was still significantly lower than the week 3 rate (Table 3). One might conclude from these data that 120-HDPE did not directly stimulate mitosis, but that such acti vi ty was the result of the wound created by the i replant procedure. However, examination of the rate of mitotic activity on an individual rete peg ba.is provides further insight (Table 4).

With the 120-HDPE Implants, the rate of mitotic activity was always highest in the rete peg adjacent to the implant material. In fact, the mitotic index for this peg *in* week 12 was nearly as high as in the first week (Fig. 31). Mitotic activity decreased rapidly in rete pegs away from the implant in week 1, but the rate had increased somewhat by week 3 (Fig. 31). This indicated that the implant was producing a chronic stimulation across several rete pegs. This stimulator effect was short-lived; by week 6, the rate of mitotic activity in the second to fifth pegs away from the implant had returned to normal. In contrast, the rate of mitotic activity associated with the control sites was spread across all five rete pegs examined, and remained elevated during the first six weeks that biopsy samples were available from control sites.

We conclude that the 120-HOPE implants provided a very mild chronic stimulus that increased the rate of mitotic activity, but that this stimulus was extremely localized and by week 12 had been restricted to cells of the rete peg immediately adjacent *to* the implant material.

The ingrowth of fibrous tissue in the 120-HDPE implants shows promise for long-term retention. Two potential problems which ultimately may interfere with the process are infection (Dasse 1984) and epidermal downgrowth (Daly and Dasse 1983). We observed both of these processes in association with the 120-HOPE implants. Bacterial colonies. adjacent to the implants and within the pores, were noted with increasing frequency during the first six weeks of the study. By week 12 bacterial colonies were

restricted to the level of the epidermis, which had, however, grown down to a depth nearly twice that of normal epidermis. Hall et al. (1975) speculated that fluid-filled pores could cause the implant to serve as a wick for bacteria. However, von Recum (1984) observed infection in only a few porous implants. Our own observations support the former hypothesis. and this wicking action may be accelerated in an aquatic environment.

The biopsy sample of week 12 revealed that the *zone* of acute neutrophilic inflammation associated with bacteria had moved deeper below the surface and was accompanied by downgrowth of epidermis which was differentiating into stratum externum. In other words, the downgrowth of epidermis appeared to be stimulated by the presence of an acute inflammatory infiltrate and halted by contact with either healthy granulation or scar tissue. Daly and Dasse (1984) hypothesized that mature collagen inhibits epidermal downgrowth. However, Grosse-Siestrup and Affeld (1984) discussed three reasons why epidermal downgrowth may not be inhibited: disturbed collagen synthesis, disturbed blood supply, and changing cellular enzyme activities at the polymer/tissue interface. Despite the downgrowth observed in the week 12 sample, we believe that 120-HDPE has Potential as a Percutaneous implant material in dolphins.

Recent studies by Daly and Dasse (1983) and Grosse-Siestrup and Affeld (1984) point to the need for percutaneous devices with different interface materials and surface structures for different cutaneous and subcutaneous tissue layers. For example, Daly and Dasse (1983) developed a percutaneous ener9Y transfer sYstem consisting of five component materials, each serving a specialized purpose, that achieved a one year survival time. However, they believed that further work is needed on the critical tissue-material interface that inhibits epidermal downgrowth.

Our study is a first step towards understanding biocompatibility of percutaneous implant materials in dolphins. Our findings highlight the need for the rapid formation of a viable biological seal to insure mechanical stability, prevent epiderma marsupialization, and provide a barrier to invasive pathogens. We are confident that longevity in cetacean skin can be achieved by selecting an implant of the proper composition and configuration. Future research will be directed towards designing a functional tag which allows tissue ingrowth, has a modulus of elasticity close to that of soft tissue, and is strong enough to withstand mechanical forces. We anticipate long-term success by using a composite device fabricated from several of the following materials: isotropic carbon, porous PTFE (Proplast II or Gore-Tex), porous polyethylene (120-HDPE or Plastipore), polyester velour (Dacron), and polyurethane (Tecoflex).

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GLOSSARY OF HISTOLOGIC AND PATHOLOGIC TERMS

Abscessation – the formation of a localized accumulation of pus, composed of white cells (neutrophils), and tissue and cellular debris. Usually surrounded by a fibrous membrane.

Basal cells – the layer of cells which line the basement membrane underlying the epidermis.

Chromatin pattern – the appearance of the chromatin (DNA) within the cell nucleus.

Collagen – a main supportive protein of connective tissue.

Congestion – excessive accumulation of blood in a tissue.

Dermal papillae – the small finger-like projections of dermis into the epidermis.

Edema – (intra- or interce lular) – abnormal accumulation of fluid.

Eosinophi ic – readi y stainable with eosin; having a red appearance in hematoxylin-eosin stained preparations.

Eosinophils – a white blood cell containing eosinophilic granules.

Epidermal downgrowth – of epidermis along the margins of a percutaneous implant.

Epidermal pearls – whorls of keratinocytes usually seen in an area of epidermal repair.

Erythrocytes – red blood cells.

Fibroblasts – connective tissue cells which form the fibrous tissue of the dermis.

Fibroplasia – the formation of fibrous tissue, as occurs normally in healing wounds and scar formation.

Germinatival cel s – the basal layer of cells underlying the epidermis which divide giving rise to the cells of the epidermis.

Giant cells – groups of macrophages forming multinucleated cells, often in response to indigestible debris.

Granulation tissue – a mass of tissue composed largely of capillaries, fibroblasts and a few inflammatory cells. A proliferative response to compensate for loss of tissue.

Hemorrhagic – description of any tissue into which bleeding has

Hyperplasia – the abnormal multiplication or increase in the number of otherwise normal cells.

Hypertrophy – the enlargement of an organ or tissue due to an increase in the size of the constituent cells.

Inf ammation – a complex series of events in response to tissue injury. Features include increased vascular permeability, exudation of fluids and leukocytic migration into the inflammatory focus.

Inflammatory cell infi trate – migration of white blood cells into an area of inflammation.

Intraepidermal microabscess – small foci of neutrophil accumulations within the epidermis.

Macrophage – a white blood cell which engulfs debris to aid in wound healing.

Mitotic activity – the relative number of dividing cells.

Mitotic figures - cells in the process of division, particularly during the phase when condensed strands of chromatin are visible (metaphase and anaphase).

Necrotic debris - dead cells and fragments of dead cells seen in an area of tissue injury.

Neutrophil - white blood cell which can release enzymes capable of digesting tissue components. Their presence in tissues is characteristic of the early stages of inflammation.

Percutaneous - passing into the dermis through a breach in the epidermis, and maintaining permanent communication with the skin surface.

Pressure necrosis - death of tissue due to insufficient local blood supply.

Purulent exudate - deposition of pus in tissues or on tissue surfaces.

Pyknotic nuclei - a shrunken nucleus with condensed chromatin. indicative of a degenerating cell.

Rete peg - the portion of the epidermis which projects into the dermis.

Sero-sanguinous exudate - an exudate containing tissue fluid. serum and blood cells.

Sinus tract - a channel or fistula permitting the escape of pus.

Squames - the outermost scale-like cells of the epidermis.

Stroma - the supporting tissue or matrix of an organ.

Ulceration - an excavation of the surface of a tissue produced by the sloughing of inflammed necrotic tissue.

A Small Vessel Technique for Tracking Pelagic Fish

KIM HOLLAND, RICHARD BRILL, SCOTT FERGUSON, RANDOLPH CHANG, and REUBEN YOST

Introduction

The advent of ultrasonic telemetry techniques for monitoring fish movements in the wild has greatly increased our understanding of the behavior and physiological capabilities of pelagic fish (Carey, 1983). The development of pressure sensitive transmitters has allowed insights into the remarkable pressure (depth) and temperature tolerances of these animals while simultaneously revealing their fine-scale horizontal movements.

Previous tracking studies involving pelagic species have been carried out using large fishing or oceanographic research vessels. Because of the high operating costs of these vessels and the heavy demands on their time, comparatively few fish have been tracked. Also, the tracks that have been made come from widely scattered areas. Thus, although valuable data have been acquired from individuals of several species, only rarely have enough replicate tracks been obtained to give a reasonable indication of the normal daily behavior of a species in a particular location. Pelagic species that have been tracked include skipjack tuna, *Euthynnus pelamis* (Yuen, 1970); yellowfin tuna, *Thunnus albacares* (Carey and Olson, 1982); albacore, *T. alalunga* (Laurs et al., 1977); swordfish, *Xiphias gladius* (Carey and Robison, 1981); blue marlin, *Makaira nigricans* (Yuen et al., 1974); mackerel sharks (Carey et al., 1981); and Atlantic salmon, *Salmo salar* (Westerberg, 1982).

This paper reports on the development of a technique for using a small vessel for the ultrasonic tracking of pelagic fish. Our system produces high-resolution data and is sufficiently adaptable and cost-effective to allow prolonged tracking efforts in a variety of situations. Because of its modest cost, a small vessel can be dedieated to a tracking projeet for extended periods. This permits acquisition of many replicate multi-day tracks. Thus, sufficient amounts of data ean be acquired to yield reliable information about the sequential daily behavior of a target species. Details of our system and methods have been included to allow other workers to adapt our techniques to their own needs.

The impetus for development of our tracking technique began when the Honolulu Laboratory of the National Marine Fisheries Service (NMFS) Southwest Fisheries Center pioneered the modem use of fish aggregating devices (FAD's) by deploying several of these buoys in Hawaiian waters in 1975 (Matsumoto et al., 1981). These deep-water FAD's have proved to be very effective and their use has spread throughout the Indo-Pacific (Shomura and Matsumoto, 1982). However, the influences of FAD's on fish behavior which result in the aggregation of pelagic fishes at these buoys are not understood. Given the importance of FAD's, the high costs associated with FAD deployment, and unanswered questions relating to stock harvesting and management, we initiated a project using ultrasonic transmitters and a small pursuit vessel to document the movements of pelagic species associated with FAD's. To date, our efforts have concentrated solely on yellowfin tuna and bigeye tuna, *T. obesus*, with fork lengths between 50 and 75 cm.

Methods

General

Our two major objectives when equipping the vessel were simplicity and redundancy. The data acquisition and recording systems were designed to emphasize shore-side data processing,

ABSTRACT—Tracking of pelagic fish has previously been conducted from large research or fishing vessels, both of which are expensive to operate. We have adapted advances in ultrasonic tracking technology to permit tracking of pelagic fish from a small (33-foot) vessel. Sportfishing techniques have been successfully employed to capture fish for tracking.

The use of a small vessel has many advantages including maneuverability in congested areas, the ability to work both offshore and close to shore, high responsiveness to changes in fish behavior, and low operating costs. Low operating costs allow the vessel to be utilized over extended periods, thereby permitting replication of experiments. High quality data on the vertical and horizontal movements of pelagic fish have been acquired for periods of up to 6 days. These techniques could be utilized to track fish inexpensively in a wide range of locations.

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thereby maximizing the use of on-board space and equipment for actual acquisition and storage of high-quality raw data. Secondary objectives were minimizing operating costs and maximizing crew comfort, thus improving our ability to track fish for long durations.

The Vessel

The R/V *Kaahele'ale* is 'a 33-foot vessel built for the U.S. Navy as a personnel boat. It was acquired by the NMFS in 1979 and modified for nearshore fisheries research, primarily telemetry. As modified, the vessel has an open-stern deck, a semi-enclosed central cabin with engine beneath, and a fully enclosed forward cabin. The stern deck is equipped for fishing and tagging. The central cabin houses the steering console and an instrument rack containing the telemetry equipment, navigation equipment, and radar. The forward cabin is air conditioned and contains two bunks, a work bench, an expendable bathythermograph (XBT) system, and a microwave oven.

The vessel is powered by a single screw driven by a GM-671[1] diesel engine through an Allison hydraulic transmission. Two 120-gallon fuel tanks are backed with a 50-gallon reserve tank. At cruising speed (11 knots), fuel consumption is 10 gallons/hour, at trolling sped (7.5 knots) it is 5 gallons/hour, and during tracking operations fuel consumption is usually less than 3 gallons/hour. The main engine alternator supplies a 24 volt main battery which powers the starter motor, the radar, and autopilot. Radios, tracking instrumentation, navigation lights, and fathometers are powered by a separate 12V DC battery bank. A 7.5 KW 120V AC diesel generator (Onan) is housed below a portion of the stern deck and powers the X3T system, the microwave oven, the forward cabin air conditioner, and an automatic 12V battery charger.

Tracking Apparatus

Transmitted

Pressure sensitive 50 KHz ultrasound transmitters were purchased from Vemco, Halifax, Nova Scotia. Two types of transmitters have been used, one with an expected operation life of up to 22 days and the other with nominal expected life of 3 days. We have found maximum open ocean operating ranges *to* be about 0.8 miles for the 3-day tags, and about 0.5 miles for the 22-day tags. The transmitters are pressure sensitive such that the pulse frequency of the 50 KHz carrier signal is directly proportional to increasing pressure (depth). Normal operating range is zero (surface) to 500 psi (370 m depth). The 22-day duration transmitters are cylindrical (8.0 cm long and 1.6 cm diameter) and weigh 27.7 g in air and 11.7 g in seawater. The 3-day duration transmitters are of similar specifications. The transmitters are equipped with magnetically operated reed switches for rapid activation and have a nylon loop at one end for use in attachment to the fish (discussed later).

Receivers

The 12V DC amplifier/receivers (CR-40, CAI Co.) are matched to the transmitters with 50 KHz crystal-controlled oscillators. These receivers amplify and convert the telemetered pulses into an audible signal. Two receivers were installed on the vessel in case one of the units failed during a track.

Hydrophore

The directional hydrophones were also manufactured by Vemco. However, a small but very significant modification was made after delivery from the factory. This modification involved the fabrication and installation of a 2 mm thick fiberglass faring over the leading face of the hydrophore (Fig. 1). This faring serves to protect the actual sensor from physical damage and, more importantly, reduces noise generated by water passing over the hydrophore. The signal/noise ratio is improved to such an extent that, usable data can be acquired at boat speeds in excess of 7 knots. We can therefore track and acquire depth data from fast moving fish. The faring also allows the boat to be driven at 11 knots without damage to the hydrophone. No reduction in operating range

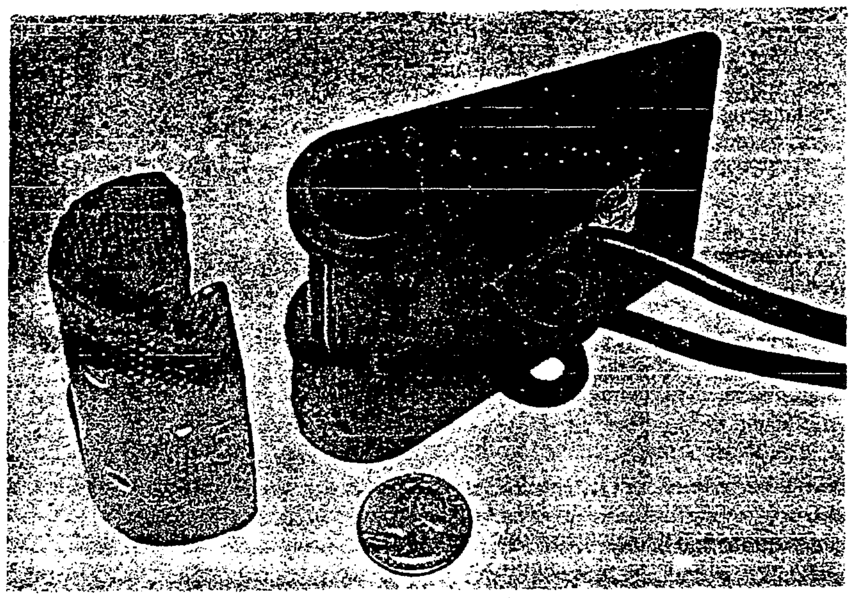

Figure 1.—The directional hydrophore is shown with fiberglass faring removed. Holes in the faring permit attachment to hydrophore body and allow water to flood the space between the hydrophore and the faring. The hydrophone sideplate has been removed to show hydrophore and preamplifier.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine fisheries Service, NOAA.

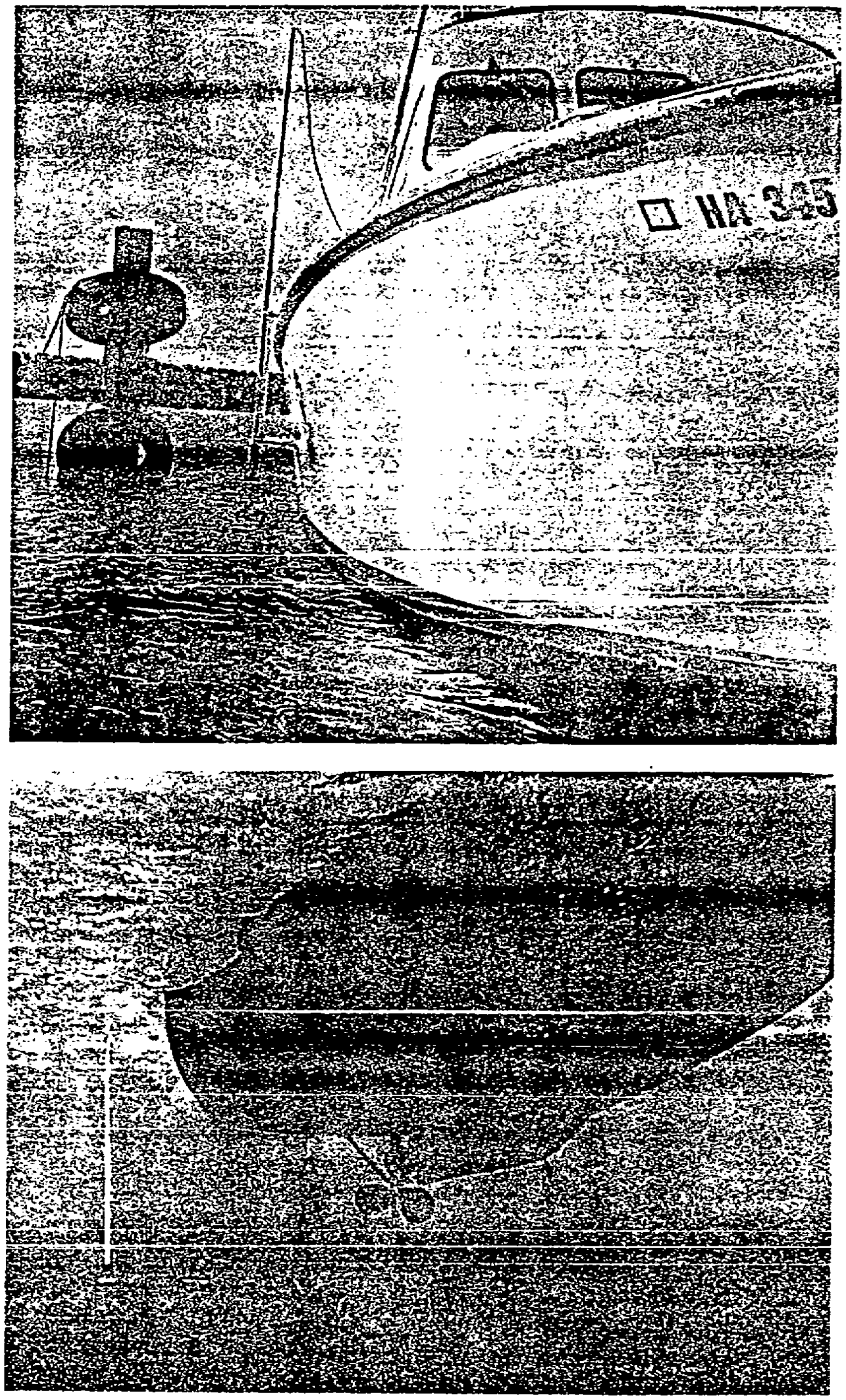

Figure 2.—Hydrophone Mounting. Top: The tracking hydrophore is in retracted position. Two triangular aluminum brackets mounted above the waterline allow the hydrophore to be lifted out of the water when not in use. Bottom: The hydrophore mount ing pole is lowered through the support brackets to a position in which the hydrophore is clear of the keel and is unaffected by turbulence from the boat hull.

was observed following installation of the faring.

The hydrophore is braced within a stainless steel bracket bolted to the end of a 10-foot length of l-inch I.D. galvanized pipe. The shielded cable from the hydrophore to the amplifier is threaded through the pipe. Shielding the cable is necessary to reduce radio frequency interference.

The hydrophore mounting pipe is deployed amidships using two triangular brackets, constructed of I-inch I.D. aluminum tubing, which are bolted, one above the other, through the hull above the waterline. The pole is free to slide through the brackets and is held in place by thumbscrews. Thus, the hydrophore can be lowered for tracking and raised out of the water when not in use. This outrigger type of mounting allows the hydrophore to run about 5 feet below the surface and 6 feet to the side of the keel where it is unaffected by water turbulence generated by the hull (Fig. 2). During tracking, the hydrophore is secured facing forward in parallel with the keel of the boar, and localizing the transmitter (i.e., the fish) is accomplished by turning the vessel.

Depth Data Logging

A data processor/frequency counter (Telonics, TDP-2) is connected to the audio output of the receiver. This processor unit provides a digital display of the inter-pulse interval which is recorded manually at regular intervals and which gives an immediate indication of the fish depth and any changes in behavior. A cassette tape recorder is also connected to the audio output of the receiver. This provides a continuous record of the telemetered depth data for tine-scale plotting and analysis ashore.

Navigation

Three types of fixes are used to determine the vessel's position during tracking. The primary navigational reference is by Loran C (Furuno LC-80). This unit provides latitude and longitude in-

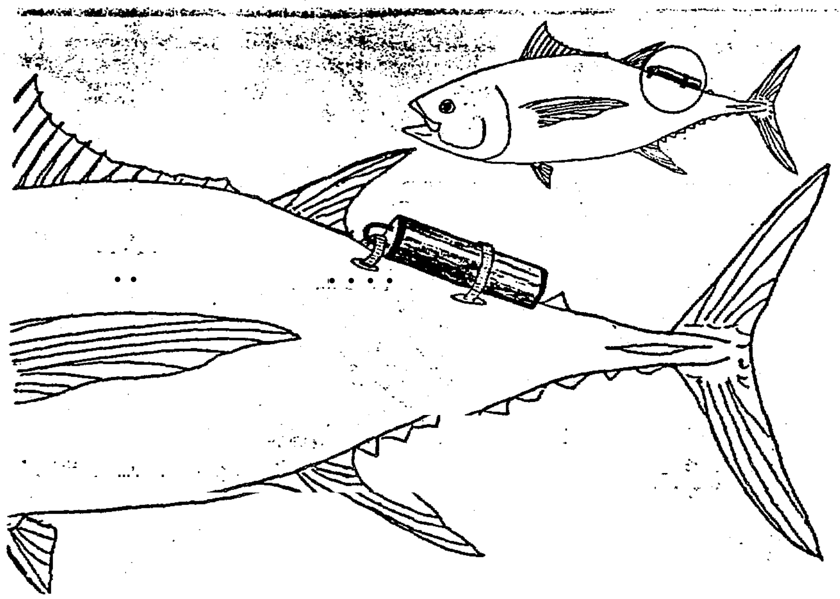

Figure 3.—The ultrasonic transmitter is attached to the dorsal surface using **two nylon tiewraps** ***inserted*** **through the dorsal musculature and pterygiophores.**

formation and also the vessel's course and speed. These latter data are useful in subsequent onshore analysis of the fine-scale movements of the fish. The waypoint storage capability of this unit also permits instantaneous information about the vessel's current position relative to starting or other important (e.g. FAD) positions. Supplementary visual fixes on charted landmarks are made using a hand-bearing compass or sextant. These visual fixes are made hourly to ensure the accuracy of the Loran C positions. The 24V DC radar unit is used to acquire accurate distances to landmarks or FAD's.

Oceanographic Information

Knowledge of the thermal structure of the ocean is essential to interpretation of the movements of the fish. Temperature data are acquired using a 1 10V AC expendable bathythermograph (XBT) system (Sippicon, Mass.). The XBT probes are deployed about every 3 hours or whenever the fish being followed moves into new waters (e.g., onshore to offshore). A bucket thermometer is used to verify the accuracy of the XBT surface temperatures.

Water current direction at FAD locations is determined by visual inspection of plastic streamers attached to the FAD's mooring chain. When operating in inshore areas (<100 fathoms) a fathometer is used to record ocean depth and to assist in determining geographic position.

Fishing and Tagging Techniques

The research vessel is equipped for both handline (drift) fishing and trolling. To date, most fish have been caught trolling. Artificial trolling lures tailored to the size of the target species are used with single "J' '-type hooks. Large reels (14/0, Penn Reels, Pennsylvania) and 130-pound test line are used so that the fish can be reeled in rapidly to reduce capture stress. The reels are set with very light drag to reduce injury to the fish's mouth. After the initial strike and run, the drags are tightened and the fish brought to the boat as quickly as possible. Occasionally, the fish are towed behind the slowly moving vessel while the remaining fishing gear is retrieved and the stem deck prepared for tagging.

The tagging cradle is located in the center of the transom. The cradle is a foam-lined, "V' '-shaped trough with one side hinged to allow variable gape to accommodate fish of different sizes. The fish to be tagged is lifted aboard, lightly wedged into the cradle and its eyes covered with a wet chamois cloth. These procedures are usually sufficient to immobilize the fish. Once aboard, species identification is verified, the hook removed, and mouth damage assessed and the fish length measured. Handling is performed without gloves which remove large amounts of mucus from the fish% surface.

Using the nylon loop embedded in one end of each transmitter, the unit is attached to the dorsal surface of the fish (adjacent to the second dorsal fin) using nylon "tie-wraps." These are inserted through the dorsal pterygiophores using sharpened hollow brass needles. Two tiewraps are used per fish; one passing through the transmitter loop, the other half way along the transmitter's length to prevent the transmitter from wobbling from side to side. After insertion through the musculature, the tie-wraps are cinched down and trimmed (Fig. 3). The fish is then released. The entire operation requires the fish to be on board between 1 and 2 minutes.

Tracking Techniques

Testing of the transmitter/receiver system has demonstrated that maximum operational range is between 0.25 and 0.8 n.mi., depending on the type of transmitter being used. Furthermore, we have established that maximum deflection of the signal amplitude meter on the CAI receiver occurs when the transmitter is within about 200 m of the vessel. Consequently, during tracking we attempt to keep the fish at just the distance where maximum gauge deflection occurs. This gives us added confidence in the accuracy of our tracks and also that we are not unduly "crowding" the fish. The directional hydrophore (and therefore the boat) is kept pointed at the fish by maximizing the audio output of the receiver. The small size of the vessel permits rapid changes of direction and rapid identification of the direction of the signal. Due to the noise reduction resulting from the installation of the hydrophore faring, a fish can be pursued at up to 7 knots if it appears to be drawing away. At higher pursuit speeds depth data recording must be temporarily suspended because the noise of water rushing past the hydrophore masks the transmitter's signal.

Data Acquisition

During tracking, four types of data are acquired: 1) A continuous tape of fish-depth data from the audio output of the CAI receiver, 2) water depth/temperature profiles (XBT), 3) water depth, and 4) navigational data. Navigational data are recorded every 10 minutes and include: 1) Tree, 2) heading/engine RPM, 3) Loran C frees, and 4) visual and radar fixes (usually taken hourly). When close enough to a FAD, its range and bearing from the vessel are also recorded every 10 minutes. A narrative commentary is compiled to assist in subsequent data analysis.

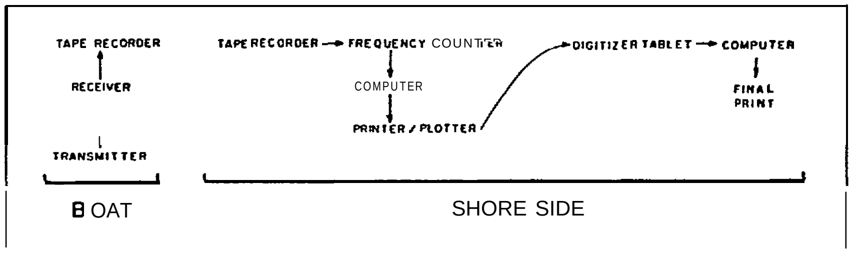

Figure 4.—Schematic representation of the data acquisition and analysis process.

Data Analysis

Vertical Data

Figure 4 summarizes the system for acquisition and analysis of vertical movement data. Once ashore, the recorded information is played from the cassettes into a Telonics TDP2 Data Processor. This processor is modified to output a +5V DC square wave each time a sound pulse is detected. A Hewlett Packard (HP) frequency counter (HP5308A) is used to time every other pulse interval. An HP 9845 computer with real-time clock converts the pulse intervals to depth and plots a graph of depth versus elapsed time. This original hard copy of the fish's swimming depth contains some erroneous points which are eliminated by tracing the depth-time profile on an Apple computer digitizer pad. This "cleaned" track (where depth is plotted every 10 seconds) is then stored on floppy disks prior to final plotting and analysis. Bathythermograph temperature profiles are superimposed on the final printouts (Fig. 5).

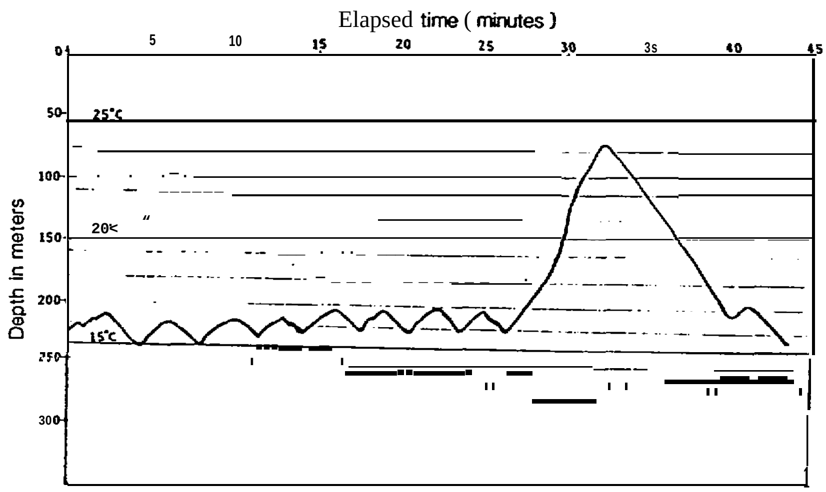

Figure 5.—A 45-minute vertical movement plot. Continuous recording of vertical movement data on cassette tapes allows both fine-scale and large phenomena to be discerned. Superimposing XBT data indicates that the swimming depth of this bigeye mna is strongly influenced by the 15° and 17° C isotherms. Depth data of this type are recorded for the entire duration of each track.

Horizontal (Position) Plotting

Because of the proximity of the tracking vessel to the target fish, no attempt is made to distinguish between the positions of the two. Plots are made on navigation and bathymetry charts based on Loran C positions recorded manually at sea. These relative positions are checked against the visual and radar fixes that were concurrently collected. Where applicable, fathometer readings are used as cross references for the other navigational data. Fine-scale movements of fish in the immediate vicinity of FAD's are plotted using manual records of the buoy's range and distance relative to the vessel.

Results

Since the installation of the tracking equipment in its current form, we have acquired 11 tracks of yellowfin tuna and 2 tracks of bigeye tuna that were caught near FAD's or near the adjacent coastline. The duration of the tracks ranged from 8 hours to 6 days.

All but one of the fish was caught by trolling. The small (6/0) size of hooks and light drag settings result in comparatively minor hook wounds. In only one instance has a fish died immediately upon release. All others have shown rapid recoveries to, what we believe, based on consistency within and across samples, is normal behavior. None of these tracks have been terminated due

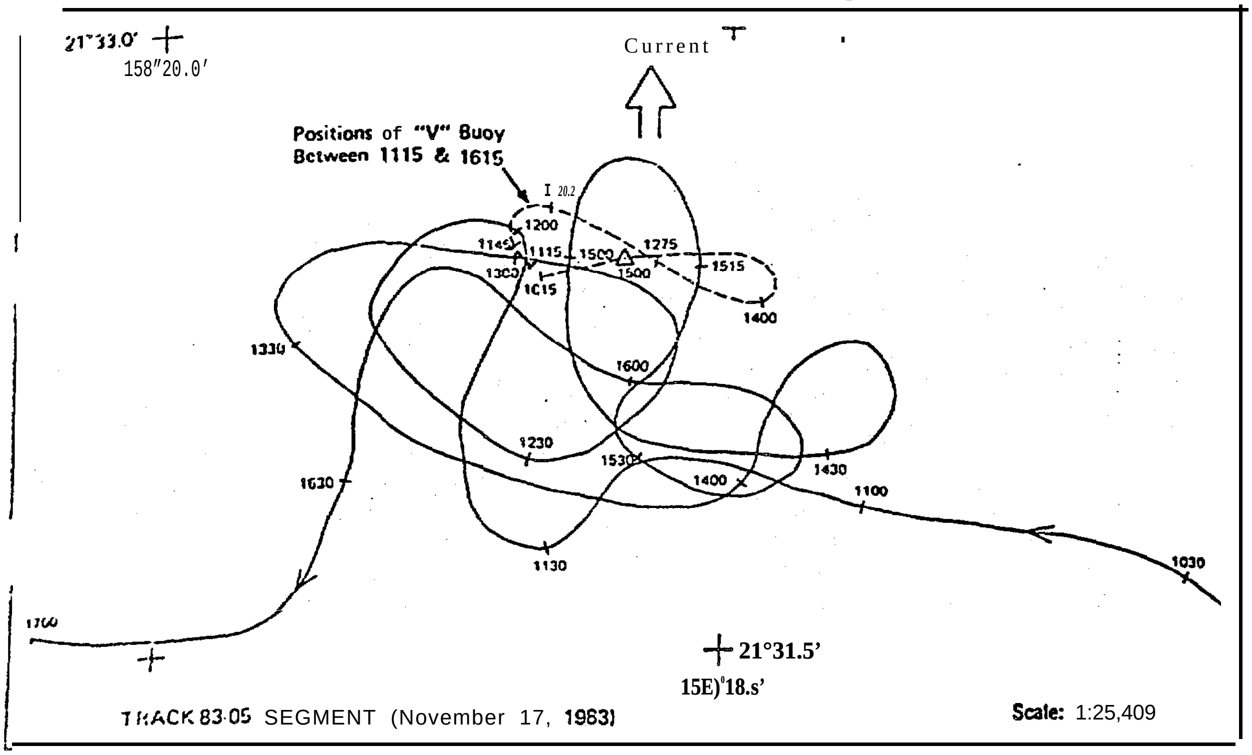

Figure 6.—Fine-scale horizontal plotting. Loran C, radar, and visual fixes allow fine-scale movements to be plotted. After arriving at FAD "V" off Waianae, Oahu, this 55 cm yellowfin tuna spent about 85 percent of the next 5 hours on the upcurrent side of the buoy. The "Figure 8" movement of the buoy can also be plotted.

to death of the fish.

Captive fish tagged with the "double tit-wrap" method and observed in large tanks at the Kewalo Research Facility of the NMFS Honolulu Laboratory were [illegible] swim normally with the school and appeared healthy after the 2-week observation period ended. In addition, a fortuitous recovery of a tagged fish by a fisherman attests to the suitability of our trolling/tagging technique. This fish was caught by a fisherman trolling near a FAD 3 weeks after we obtained a 36 hour track of it.

Discussion

Although almost all of the technology incorporated in the current research had been previously developed and utilized by others, we feel we have made significant advances in successfully adapting these techniques to a small vessel. Also, the ability to chase pelagic, highly mobile fish at 7 knots in the open Ocean and still simultaneously collect vertical movement data is an innovation. We believe that our cassette recording and subsequent plotting of the vertical movement data has produced higher resolution vertical movement data than have previously been published. The continuous depth record has revealed phenomens (such as rapid vertical excursions and small scale oscillations) that manually collected data would have missed (Fig. 5). When the XBT data are superimposed on the tracks, much of the vertical behavior shows correlations with temperature (Fig. 5). Similar temperature influenced behaviors have been observed in bluefin tuna, *Thunnus thynnus* (Carey and Olsen, 1982).

The Loran C system of geographic plotting, when referenced with visual fixes, provides high resolution positioning of both large-and small-scale movements (Fig. 6). When Loran information is used in conjunction with visual fixes and radar ranges, small-scale movements of both the fish and FAD's can be plotted. Knowledge of the relationship between signal amplitude and transmitter distance lends confidence to the precision of the small-scale plots.

The small size of the tracking vessel has proved to have several advantages. For example, while able to pursue fish in the open ocean, the maneuverability of the vessel has also permitted unobtrusive data collection even when in the midst of many other vessels fishing at the FAD locations. Also, fish have been tracked to within 200 m of shore where larger vessels could not safely go. Similar situations occur in other locations such as straits, bays, lakes, and estuaries where tracking studies might be worthwhile but where large vessels would be too cumbersome. A vessel such as ours is capable of continuously following a fish both when it is moving in inshore (e.g., estuarine) waters and also when it moves offshore where it would be beyond the range of fixed hydrophore arrays or of very small vessels such as skiffs.

Of course, small vessels are not suitable for mid-ocean work or offshore locations beyond refueling range. However, they could be used very successfully in association with a larger mother ship which could be performing other tasks while the small pursuit vessel was tracking.

The comparatively low hydrodynamic and mechanical noise generated by our small hull allowed the hydrophore to be attached directly to the side of the boat, thereby precluding the need for complex towed arrays such as have been deployed in some other tracking studies which used large vessels. Similarly, because a small vessel is very maneuverable and can accelerate quickly, the hydrophore can be permanently locked in an orientation parallel with the keel and the entire boat turned to accomplish maintaining" contact with the target fish. This high responsiveness eliminates the need for rotatable or multi-head hydrophore systems such as have sometimes been used in the past.

Much of our tracking work has been conducted out of small boat harbors with depths of 2 fathoms or less and which would have been inaccessible to larger fishery research vessels. Each 24 hours of tracking consumes about 70 gallons of fuel. At this rate our vessel can track for at least 3 days without refueling, which can be conducted at any nearby small boat harbor. We have found crews of three sufficient for all phases of the field work. This, combined with the low fuel costs, makes the total operating cost of each tracking expedition extremely modest when compared with the $5,000 to $15,000 daily costs of large research vessels or commercial fishing boats. Our modest expenses enable the vessel to be dedicated to the tracking project for extended periods. This allows replicate tracks of different species from various locations. Also, because the vessel is committed to the tracking project full time, we can take advantage of short term increases in fish abundance and avoid fishing when fish are not abundant. Our ability to use sport fishing techniques to obtain fish for tracking indicates that labor-intensive trapping methods or expensive bait-boat techniques are not obligatory for a successful tracking program.

The small size and modular nature of the actual tracking equipment is such that it could be quickly installed on almost any suitable vessel. The major installation requirement is the bracing of the hydrophore brackets to the hull. However, since the bracket mountings are well above the water line, even this aspect of the installation could easily be repaired when the tracking is completed. The availability of an AC power generator has proved to be essential. Not only does this provide XBT capabilities but also allows improvement in crew facilities such as hot food and air conditioning.

The two major limitations of our system are fuel capacity and crew fatigue. We have solved the former by refueling during prolonged tracks. However, this technique may be unique to our project because of the proximity of small boat harbors and the rhythmicity of behavior of some of our fish which has allowed us to relocate them after temporary suspension of tracking. Crew fatigue is inevitable with a small vessel after a few days on water. We feel that in our case this could be substantially remedied by using only a slightly larger vessel (e.g., 40-45 ft) which would be somewhat more spacious and comfortable and yet which would retain the desirable characteristics of maneuverability and low operating costs. Another possible technique would be the use of a shuttle vessel to exchange crews on the pursuit vessel.

We are currently unable to be completely sure whether or not the fish being tracked is traveling alone or in a school. We feel this shortcoming will be rectified by the installation of a chromoscopic fish tinder.

In general terms, however, we feel that we have developed a cost-effective technique for acquiring high-quality tracking data which could be adapted to a range of small vessels operating in a variety of situations and locations. This, in turn, will result in a significant increase in our understanding of the normal behavior of commercially important fish species about which not much is currently known. Such an increase in our understanding will improve both management and fishing techniques

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MARINE MAMMALS AND THE BIOSPHERE

REPORT

OF THE CONFERENCE

ON THE

USE OF REMOTE SENSING

OF

MARINE MAMMALS

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Santa Barbara Institute for Environmental Studies
March 21-22, 1981
Santa Barbara, California

Sponsored by

The Center for Environmental Education
Washington, D.C.

SUMMARY

A conference on the use of remote sensing for the study and management of marine mammals was held on March 21 and 22, 1981 by the Santa Barbara Institute for Environmental studies in Santa Barbara, California. The conference, sponsored by the Center for Environmental Education of Washington, D.C., brought together more than twenty experts from the United States and England. Topics discussed included: (1) the possibilities for remote sensing of marine mammals: (2) why available techniques have not been fully utilized in the past; (3) the role of marine mammals in global ecology and in what way the study of the . distribution and abundance of marine mammals is significant to an understanding of life from a planetary perspective; and (4) the potentials of remote sensing in the management and conservation of these animals. Several recommendations emerged. These are:

1. A program of research should be established to determine the relationship between major global variables and the distribution and abundance of marine mammals.
2. The feasibility of detecting marine mammals or marine mammal populations in their centers of distribution using remote sensing should be explored.

3. In particular, the feasibility of detecting whale populations with remote sensing in the southern oceans adjacent to the Antarctic continent should be determined. Special attention should focus on requirements in terms of wavelengths, spatial resolutions and temporal sampling, and cost-effectiveness vis-a-vis surface sampling.

4. Existing information concerning habitat selection by different species of marine mammals and the co-occurrence of certain oceanic phenomena with their distribution should be coupled with remote sensing of marine mammals by aircraft and satellite to determine their abundance (particularly at their centers of distribution), and to provide technical support for major management issues.

5. A program should be established to quantify the fluxes of carbon, nitrogen and phosphorus in the major upwelling regions. In particular these fluxes should be determined for the ice-dominated southern oceans and boreal seas because they are among the major areas of oceanic productivity, and because management issues concerning the production and harvesting of organisms of commercial value focus, to a large extent, on these oceans.

6. A program should be established to determine the relationship between temporal changes in the antarctic and arctic sea ice, the upwelling of nutrients in the southern and boreal oceans, the production of plankton, and the production of pinnipeds and whales. The marine mammal scientific community should:
   a) consider how to use existing data sets and
   b) explore the use of the new techniques.

7. Remote sensing should be investigated and tested for its ability to provide correlative measures of the spatial and temporal patterns of arctic and antarctic ice packs, ocean water characteristics, and occurrence of phytoplankton and zooplankton patches.

8. The combination of knowledge of habitat selection by different species of marine mammals should be coupled with remote sensing by aircraft and satellite to determine abundance by species especially in the southern oceans and boreal seas.

9. The potential of geostationary satellite receivers for data collection, particularly of the radio tracking of marine mammals, should be investigated.

10. The available observation techniques should be employed in concert, as a “hierarchy of information systems”, each

providing information at a certain temporal and spatial scale.

11. A lead agency is needed for the technical development of remote sensing of marine mammals; NASA should be this lead agency.

INTRODUCTION

There is a growing recognition that life on the Earth is indeed a planetary phenomenon, that the properties of the Earth's atmosphere, oceans and sediments have been greatly altered in the past and are, to a great extent, determined by life. On the other hand, there is also a growing recognition that life is sustained over a long period by a planetary-scale system; it is the interactions of the Earth's major regions in the cycling of chemical elements and flux of energy that provides a system in which life persists, a system called the Biosphere (meaning that part of the Earth where life exists).

In this large-scale living system, there are few creatures that migrate over great distances, experiencing a great variety of the Earth's regions. Along with human beings and migratory birds, marine mammals are the Earth's great wanderers. Some of the great whales, for example, move annually from the tropics to the polar regions. As such, marine mammals are biological indicators for most of the world's oceans, for basic ecological processes, and for changes in these processes; the extent to which they can function as such indicators is not known, They may affect global ecological processes in a significant way; the extent of this effect is also unkown. Thus it would seem that the marine mammals have a special place in the biosphere.

Among living creatures, some marine mammals are relatively abundant. For example, there are more than a million harp seals, and more than 15 million crabeater seals, worldwide; some of the porpoises and dolphins are thought to number in the tens of millions. However, all marine mammals together represent a small fraction of the material in the biosphere or even of the total living organic matter.

An intriguing question is, "To what extent do marine mammals play a major role in marine ecosystems and in the biosphere as a whole?" On a local basis, some marine mammals have a great impact. For example, along some areas of the Alaskan and California coasts, sea otters greatly alter the abundance of kelp and of shell fish and have an indirect influence on many other marine organisms.

On a regional basis, scientists conjecture that marine mammals may have had a major effect on the abundance of other species. For example, high latitude oceans such as the Bering Sea and southern ocean which surrounds the Antarctic Continent are among the Earth's major areas of marine biological productivity, and are major feeding areas for several species of whales and seals. It is speculated that commercial harvesting of whales in the southern ocean during the 19th and 20th centuries may have greatly altered the abundance of krill which is the food for whales, indirectly affecting the abundance of birds and seals which, along with the whales, feed on krill in the southern oceans.

The local coastal impact of sea otters in the Northern Hemisphere and the possible large scale effects of whales in the southern ocean raise the possibility that marine mammals might have even larger scale global effects on the biosphere. Therefore, the relationship between marine mammals and global ecological phenomena is a topic that might be of considerable importance to the study of life from a planetary perspective.

As nature's great wanderers, marine mammals may be integrators of global variables, and may serve as indicators of the status of certain factors of global concern. From a practical standpoint, the study of the occurrence in marine mammals of various environmental toxins produced by modern technology might aid our understanding of the fate of these compounds in the sea. The presence of such compounds in marine mammals may indicate atmospheric and oceanic fluxes of these and other materials.

Compared to other species, whales, in particular, have an almost global range and, along with other marine mammals, are likely to be affected by events at a global scale. Many marine mammals feed in major upwelling areas and in high latitude regions near ice packs. Factors much more readily measured by remote sensing than marine mammals themselves, such as the distribution of the ice, pack, ocean temperature and currents, and the distribution of phytoplankton pigments serve as important determinants of marine mammals' migration and persistence, and of their distribution and abundance. Studies of the changes in these factors could serve as an aid in the understanding of the distribution and abundance of marine mammals.

As indicated by the more than 70-year history of the North Pacific Fur Seal Commission, the 20-year history of the International Whaling Commission, of international treaties governing the harvesting and management of seals and other marine mammals, and by national laws such as the U.S. Marine Mammal Protection Act of 1972, marine mammals are of important concern worldwide. While there is much interest in the conservation and wise management of these animals, little is known about the factors that determine their distribution, abundance, population growth, and survival.

THE CONFERENCE

The Purpose

For more than a decade remote sensing* has been discussed, examined and used from time to time in the study of marine mammals. In spite of its great potential, remote sensing remains greatly under-utilized. Its practicality has been questioned, funding limited, and communication among agencies and administrators about the utility of the available techniques sorely lacking.

*A technique for monitoring the earth's resources utilizing electro-magnetic radiation that is reflected, emitted, or absorbed by the earth's surface, and measured from air or space platforms.

Because remote sensing seems to offer the greatest hope for major advances in the study or management of many marine mammals, scientists who study these organisms must work together to promote the funding, further development, and implementation of remote sensing. For these reasons, a conference was convened to explore the means by which a more complete and integrated use of remote sensing of marine mammals can be advanced. The conference on the use of remote sensing for the study and management of marine mammals was held on March 21 and 22, 1981 by, the Santa Barbara Institute for Environmental Studies in Santa Barbara, California. The conference, sponsored by the Center for Environmental Education of Washington, D.C., brought together administrators of programs related to life from a planetary perspective, administrators of programs dealing with the management of biological resources, scientists involved in remote sensing of planetary scale phenomena, experts in the biology of marine mammals and experts in the use of certain specific techniques already employed in the study of marine mammals. The topics discussed included: (1) the possibilities for remote sensing of marine mammals; (2) why available techniques have not been fully utilized in the past; (3) the role of marine mammals in global ecology and in what way the study of the distribution and abundance of marine mammals is significant to an understanding of life from a planetary perspective; and (4) the potentials of remote sensing in the management and conservation of these animals.

Present Techniques

Among the techniques that have been used to mark and follow marine mammals, to study their distribution and behavior, and to estimate their abundance are: (1) direct visual observations; (2) identification of individual whales by natural marks on their bodies; (3) attachment of passive markers; (4) attachment of radio markers; (5) remote sensing, including UV, IR, and visual photography from aircraft; and (6) the use of indirect indices such as the presence of food or of ice floes.

Radio tags, although difficult to implant and often short lived, have yielded new insights into the biology of marine animals. In the last five years important advances have been made in the technology of these tags which, in some cases, have already yielded significant new information.

The entire suite of remote sensing techniques, coupled with current knowledge of the biology and ecology of marine mammals, and their relationship to physical and environmental chemical factors, could be used to provide significant advances in the study of these organisms. On the other hand, a study of the ecology of marine mammals without remote sensing is likely to yield relatively little information at great expense.

General Information Needed

In spite of their large individual size, marine mammals are difficult to study. They are elusive; they move quickly, dive deeply, and are difficult to recognize as individuals. Although

they have been studied for decades, there are few marine mammal populations for which even the most basic aspects of their ecology are well understood.

Information needed to understand the population distribution, temporal changes and the ecology of marine mammals include:

Oceanic characteristic such as ocean water temperature profiles, concentrations of chlorophyll, and correlations between the distribution of marine mammal species and other oceanic properties.

. Frequencies of appearance, geographic location of mammals, and relationship of these locations to other features of the environment.

Group *size, sex,* and size structures of populations (that is, the relative number by sex and by size within a group or within a population), and migratory Patterns including rates of travel, and *location of* major feeding and breeding areas. There is some evidence from recent studies that chlorophyll, as an index concentration of phytoplankton, may be correlated with the distribution of certain marine mammals. In addition, oceanic habitats of marine mammals may be correlated with ocean temperature and salinity gradients, and these may be observed remotely to provide evidence of the locations of marine mammal habitats.

. Annual pattern of oceanic ice packs. This is of particular interest because it can be readily observed from satellites and has been done so from a number of weather, military, and research satellites. Because some marine mammals feed at the edges of ice packs, a knowledge of their annual patterns may be a useful correlative in the study of the distribution and abundance of marine mammals.

Recommendations

Several recommendations emerged. These are:

1. A program of research should be established to determine the relationship between major global variables and the distribution and abundance of marine mammals.
2. The feasibility of detecting marine mammals or marine mammal populations in their centers of distribution using remote sensing should be explored.
3. In particular, the feasibility of detecting whale populations with remote sensing in the southern oceans adjacent to the Antarctic continent should be determined. Special attention should focus on requirements in terms of wavelengths, spatial resolution and temporal sampling, and cost-effectiveness vis-a-vis surface sampling.
4. Existing information concerning habitat selection by different species of marine mammals and the co-occurrence of certain oceanic phenomena with their distribution should be coupled with remote sensing of marine mammals by aircraft and satellite to determine their abundance, particularly at their centers of distribution, and to provide technical support for major management issues. An important example is the relationship of whales, seals, and other consumers to

the harvesting of krill in the southern oceans.

5. The production and distribution of food organisms for marine mammals are ultimately determined by the fluxes of major nutrient elements and of physical oceanic conditions such as temperature and water flow. A program should be established to quantify the fluxes of carbon, nitrogen and phosphorus in the major upwelling regions. In particular, these fluxes should be determined for the ice-dominated southern oceans and boreal seas because they are among the major areas of oceanic productivity, and because management issues concerning the production and harvesting of organisms of commercial value focus, to a large extent, on these oceans.
6. A program should be established to determine the relationship between temporal changes in the antarctic and arctic sea ice, the upwelling of nutrients in the southern and boreal oceans, the production of plankton, and the production of pinnipeds and whales. A four-year data set exists that would allow a preliminary analysis to be carried out. The analysis could determine the feasibility of establishing a remote sensing program in conjunction with other efforts, such as the BIOMASS program, to facilitate the identification, distribution, abundance and productivity of krill and other important species in the southern oceans. Advances have been made in the last decade in the passive and active remote sensing of oceans and ice, including microwave, radar, etc. The marine mammal scientific

community should:

(a) consider how to use existing data sets and

(b) explore the use of the new iques.

7. Remote sensing should be investigated and tested for its ability to provide correlative measures of the spatial and temporal patterns of the arctic and antarctic ice packs, ocean water characterist cs, and occurrence of phytoplankton and zooplankton patches.

8 The combination of knowledge of habitat selection by different species of marine mammals should be coupled with remote sensing by aircraft and satellite to determine abundance by species, especially in the oceans and boreal seas where they could most usefully serve as ecological indicators

9. The potential of geostationary satellite receivers for data collection, particularly of the radio tracking of marine mammals, should be investigated.

10 available observation techniques should be employed in concert, as a "hierarchy of information systems", each providing information at a certain temporal and spatial scale.

11. A lead agency is needed for the technical development of of marine mammals; NASA should be th s lead agency

APPENDIX

RECOMMENDATIONS CONCERNING TECHNICAL ASPECTS OF REMOTE

Remote Sensing of Marine Mammals

Although user needs, legal mandates and technolog cal developments for remote sensing of marine mammals have been previously identified in various workshops and documents, these recommendations reflect the current availability of micro-miniaturized electronics and vastly improved attachment systems for radio tracking and a wide spectrum of remote sensing tools. Radio transmitters for aircraft and surface tracking are currently available for short-term studies and satellite transmitters could be fabricated with sufficient commitment of funds. Location, distribution, behavior, activity and habitat-use pattern, habitat characterization, physiology and abundance data can be acquired by remote sensors.

Current radio tracking transmitters are of satisfactory size and weight for aircraft tracking of large cetaceans but further reductions are necessary for transmitters designed to be received by satellites. The stability requirements of current satellite systems are difficult to achieve. Improved efficiency in size, weight and, above all, energy requirements could be achieved if satellite system requirements could be relaxed. For most applications, users would be willing to give up locational accuracy (up to several tens of kilometers in some cases in exchange for significantly relaxed stability requirements.

In general, processing times, data quality, etc. from satellites are not critical problem areas. Improvements aimed at easing requirements or specifications imposed on animal packages are important. For example, improvements and/or modifications of algorithms that permit location with less stable oscillators to achieve comparable accuracies would be invaluable. changes or alterations that permit reductions in accuracy are also worthwhile in many applications.

A refinement that would be useful when significant numbers of signals from conventional radio tags are to be received by a single receiver is the addition of identifying characteristics to the transmitted signal to permit distinguishing between tags, i.e., individual animals. This identification is implicit in the requirements for satellite systems (ID coding).

Although power sources are available for short term radio tracking, improved efficiency of battery power sources to increase lifetime and reduce size and weight requirements of packages is in all cases desirable. It is recommended that research be initiated to explore new technology and evaluate existing devices for improvements, to investigate the feasibility of development of alternate energy sources (e.g., salt water, temperature differential, mechanical to electrical conversion, etc.), and to determine degradation in efficiency of solar cell charging over extended periods within the marine mammal environment.

A useful and available technique for achieving extended lifetime combined with reduced size and weight is thorough, intelligent utilization of energy through reduced duty cycles

and/or use of optional times to minimize power expenditure. For example, micro-processors could be programmed with orbital parameters to enable transmission periods to coincide with satellite overpasses. Additionally, the control of duty cycle (e.g., 4 hrs/day) could be optimized through the knowledge of behavior patterns to reduce wasted expenditure of energy.

Improvement in power efficiency and overall performance is heavily contingent on antenna performance. Techniques and configurations that offer efficient radiation patterns appropriately oriented for surface, aircraft or satellite application.S and are inherently independent, or decoupled from background surfaces, must be developed and tested. To the extent possible, simulations should be carried out. Failure to address this *issue* would result in systems exhibiting frequent loss of communications (outages) or requiring higher power transmitting systems to compensate for poor antenna performance. High-gain ADF aircraft receiving antennae for high frequency (HF) bands need to be developed.

The addition of telemetry to radio tags on animals is needed to provide concurrent information on environmental (depth, water temperature, etc.) and physiological (heart rate, CO_2, etc.) parameters. Development is needed of suitable sensors for such measurements, and systems of temporary storage (and integration, sequencing, etc.) of this information in the tag, as well as ways of delivering the data (encoding the tag signals) . Complementary decoding systems for the tag-receiving systems are also needed.

For surface and aircraft monitoring at very high frequency

(VHF), the need exists for rapid-responding automatic direction finders such as those available at HF ranges to determine bearing during short surface periods. For orbiting satellite systems, the location function is inherent. In the case of satellite systems, improved receiver sensitivity would reduce the equivalent isotropic radiated power (EIRP) required to be produced by the radio tag thus making it easier to live within weight, size and power constraints. For example, a reduction of required EIRP by a factor of two translates directly to a reduction of battery size by a factor of two, all else remaining equal. The satellite receiving system capacity may need expansion if reliable satellite transmitters become available for animal tracking.

The requirements for radio tag attachment systems fall into two categories, depending on the desired duration of the study: *short-term or long-term.* The attachments *now* in use appear to be sufficient for short-term studies (days to two or three months). For long-term retention in animals, however, there needs to be careful assessment of the effects of attachment mechanisms on the animal tissues, materials of the tags, and methods of application. Studies should be initially conducted on laboratory animals, such as pigs, along with detailed studies of rejection mechanisms in cetacean skin and blubber. Then, from these assessments, shapes and materials should be chosen to minimize the effects that contribute to tag rejection and hydrodynamic drag and to encourage natural processes that would help hold tags in place. A 13-month tag retention is suggested as the optimum goal for a long-term tag.

Consideration should be given to further developing applications of sonic tracking techniques for localized movements, either by direct data collection from surface vessels or by buoy data collection and retransmission to satellites.

Efforts should be made to investigate the use and improvement of geostationary satellite receivers in order to make it possible to employ their data collection capabilities to track marine mammals and to benefit from their constant visibility.

Automated data collection equipment should be developed for use with conventional aircraft and surface radio tracking receiving systems which will couple with and record receiving platform navigation parameters.

Because the most enduring systems for supporting radio tagging are the operational Data Collection Systems (DCS) operated by NOAA in cooperation with France (Service ARGOS), a more precise definition of the criteria under which marine mammal activities will be judged eligible to *use* these systems is needed. This should take the form either of acceptance of animal tracking as a legitimate operational application or of a clear statement of conditions that must be met for an activity to be considered eligible as *an* experiment. At present, permission has been granted for animal tracking experiments of about six month’s duration.

It is recommended that an umbrella agency or organization take the lead in a technical development program for remote sensing of marine mammals; NASA is suggested as the logical agency to assume that role.

It is also recommended that a technical advisory group be created to oversee and provide guidance for any coordinated development effort concerning remote sensing of marine mammals.

Direct SenSing of marine mammals from satellites, rather than sensing indicators or correlates of their presence (indirect sensing), may not be feasible at this time. However, the use of high resolution sensors, such as radar, should be explored as they become available. Satellite linked buoys with active sonar or passive acoustic arrays might be deployed to detect and rebroadcast marine mammal sensing data. Certainly direct sensing (either remote or local) must be employed to verify and calibrate indirect sensing studies. Both direct and indirect remote sensing from aircraft would benefit from: (1) fine spatial and spectral resolution films and filters, (2) development and testing of non-photographic techniques, and (3) testing of appropriate wavelength sensors for obtaining census data and habitat characterization. Photo image enhancement processing should be considered as a method for deriving maximum data from current photographic sensors. It should be remembered that it is often sufficient to locate aggregations rather than individuals. The essential component to the realization of the remote sensing goals possible with proposed developments is the creation of an integrated program of marine mammal research focused on a specific habitat characterization.

Remote Sensing of Marine Mammal Habitats

Marine mammals live in a variety of environmental contexts that are being studied using satellite sensors by researchers

who have no special interest in the marine mammals themselves. Examples include studies of ice, ocean thermal fronts, primary production, and population processes. Such studies use various remote sensors and are assessing and defining important characteristics of the habitat. To varying degrees this information is necessary for a full understanding of the ecology of marine mammals.

It is recommended that those programs and sensors that provide data relevant to understanding marine mammals should be explicitly recognized to the end that such recognition reinforces the continuation of those activities. It needs to be emphasized that information derived from satellites is particularly important in that it provides synoptic mesoscale environmental data not otherwise obtainable.

The general class of oceanic phenomena of interest includes ice - its formation, structure, age and disappearance, fronts (there are a wide variety of these) - water masses, chlorophyll (type and quantity), salinity, and suspended sediments. Some characteristics are measured directly (e.g., temperature), and others inferred (e.g., currents). Critical sensors include Scanning Multi-Channel Microwave Radiometer (SMMR), Coastal Zone Color scanner (CZCS), and Advanced Very High Resolution Radiometer (AVHRR). Research is needed both to integrate existing remote sensor techniques with current marine mammal studies and to develop new techniques to determine the optimum resolution, their required “platforms” and their accuracy. A wide variety of available techniques needs to be tested.

Indirect sensing systems presently exist to measure some parameters. These are:

PARAMETERS	SYSTEM
Habitat/w temp.	AVHRR
Chlorophyll habitat	C ZCS
Temperature, bottom topography	SNMR

All of these techniques may be used to describe and delineate the habitats of marine mammals. The synopticity of satellite-derived data allows estimates of extent and variance over time and space of these habitats. sensors may be flown on aircraft and on orbiting platforms. The present status of these sensors shows that few are completely operational [Tables 1-3). The CZCS is presently operated in an experimental mode and has exceeded its projected life by 18 months. As this is the only satellite-based chlorophyll sensor, serious consideration should be given to ensuring the launch of another sensor in the immediate future.

Presently developing technology includes laser-pulsed systems (LIDAR). LIDAR systems are aircraft-borne systems that potentially can be used to measure ocean temperature, salinity, and chlorophyll. Such systems might be used in conjunction with image enhanced aerial photography to investigate the fine-scale oceanographic parameters and the distribution, school size, individual size, frequency distribution, and spatial arrangement of marine mammals.

It should be stressed that in many of these areas, the existing data bases are voluminous and need only be analyzed to produce marine mammal data. Infrared and CZCS data have been

collected for at least the last two and a half years using the Nimbus 7 research satellite. In some instances, contemporaneous surface data *exist* that speak directly to the problem of the delineation of the oceanographic habitats of marine mammals.

Common needs for data by various, otherwise separate, research groups should be identified, and the data made available as appropriate to all interested parties. The postponement of the National Oceanographic Satellite System (NOSS) has not diminished the needs for the establishment of operational modes of interaction using whatever satellite data are available at any particular time.

The full development of any marine mammal ocean habitat program mandates the development of interactive data bases and interactive analytic systems. A critical need that requires examination is the type of inter-institutional communication necessary to facilitate such development.

Table 3

Geostationary Environmental Satellites
Communications and Weather

NAME	COVERAGE	PRESENT LOCATION	INSTRUMENTS	RESOLUTION	DATA PRODUCTS
SMS-2 GOES -1 GOES-2 GOES-3 GOES-4 GOES -5	Full Oisk Every ½ Hour ½ Earth's Surface	75% 107°W 133°W (Standby) 135°W 85°W (Check-out)*	Visible and Infrared. Spin-Scan Radiometer (VISSR) Channels 0.55 - 0. 7oum 10.50 - 12.6um	Visible - 1 km Infrared - 8 km	Day/Night Cloud Cover Wind Fields
GMS (Japan)		140°E	Same	Visible-1.25km Infrared-5km	
METEOSAT (European Space Agency)		0°	Same Channels plus additional channel for Watervapor	Visible-1.25km Infrared-5km	
USSR GOES	To be launched in 1981. Approximate location will be 70°E.				
GOES-4 GOES-5	Launched Sept. 9, 1980 Launched May 22, 1981		VISSR Atmospheric sounder (VAS) Channels 0.55 - 0.73um 3.73 4.28 6.71 7.25 11.10 12.7 - 14.7	VIS : IR: 8 km	Day/Night Cloud Cover Surface Temperature cloud H_2O Temperature Sounding Wind Fields

All Altitudes 35,780 km. *As of June 30, 1981.

Table 1

Marine-Related Sensors on Sun-Synchronous
Environmental Satellites

NAME	SENSOR	CHANNELS	DERIVED PRODUCT	TIMATED ACCURACY
ANDSAT 3	lultispectral icanner (MSS)	0.5 - 0.6um 0.6 - 0.7um 0.7 - 0.8um 0.8 - 1. lum	Visible and Infrared (RD) Signatures of Terrestrial, Aquatic and Nearshore Marine Regimes	NA
.ANDSAT D	'hematic Mapper	0.45 - 0.52um 0.52 - 0.60um 0.63 - 0.69um 0.76 - 0.90um 1.55 - 1.75um 10.4 - 12.5um	Same Products as LANDSAT 3 Plus Surface Temperature	'o be launched in 1982
'IROS-N Series (NOAA-A rhru G)	Advanced VHRR (AVHRR) Note: NOAA Series Channel 10.55-11.5 Channel 5 Only on D, F and G	0.55 - 0.90um 0.725- 1.10um 3.55 - 3.93um 10.5 - 11.5um 11.5 - 12.5um	Oay and Nighttime Cloud nd Surface Mapping, Surface Water Delineation, SST	SST-0 .2°C sensitivity to Relative Changes
NIMBUS-7	Scanning Multi-Channel Micro-Wave Radiometer (SMMR)	6.63, 10.69, 18.0, 21.0, 37.0 G Hz Dual Polarization	SST Sea Surface Wind Speed	1.5°C 1 m/s
	Coastal Zone Color Scanner (CZCS)	0.43 - 0.45um 0.51 - 0.53um 0.54 - 0.56um 0.66 - 0.68um 0.70 - 0.80um 10.5 - 12.5um	Marine Chlorophyll and Sediment Distribution and Sea Surface Temperature	Parameters presently Under Investigation*
DMSP Block 5D	Operational Line Scan System (OLS)	0.41 - 1.1um 8 - 13um	Same as TIROS-N	Somewhat Lower than TIROS-N

Table 2

Oceanographic Satellites

NAME	ALTITUDE	ORBIT PERIOD	INCLINCATION	INSTRUMENTS	DATA PRODUCTS	ESTIMATED ACCURACY
GEOS-3	843 km	101.7 min. 14.2 orbits per day	115°	Radar Altimeter	Marine Geoid Significant Wave Height Sea Surface Topography	± 1-2 m ± 10% ± 20 cm
SEASAT	790 km	100.8 min. 14 orbits per day	1-8°	Radar Altimeter Synthetic Aperature Radar (SAR) Radar Scatterometer (SASS) Scanning Multifrequency Radiometer (SMMR) Visible-IR Radiometer (VIRR)	Now inoperable. Data taken for three months, June - Oct. 1978	

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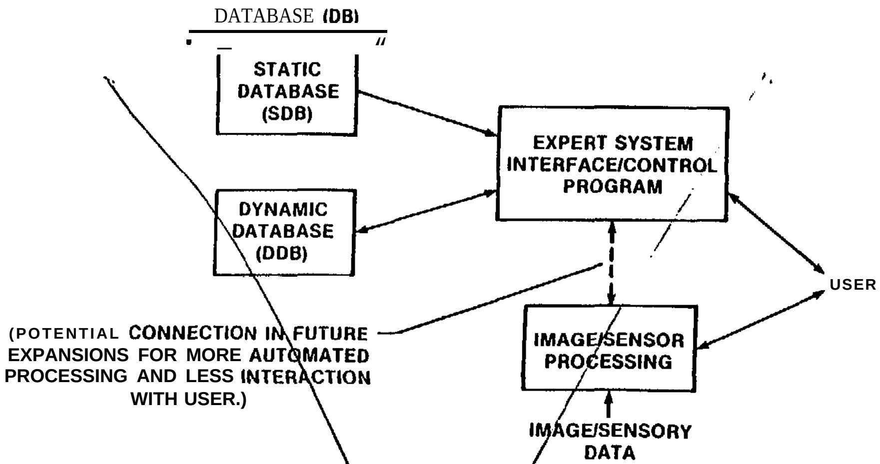

Figure 3. *Organization of prototype*

that prototype interactive, semi-automatic processing is to be supported by an expert system. Figure 3 shows the proposed organization of the prototype. The database consists of two parts: a static data base (SDB) and a dynamic data base (DDB). The SDB contains the knowledge base (facts and inference rules) which represents the current understanding of the problem domain. That knowledge base is likely to be made up of subjective knowledge of experts plus quantitative or statistical results of studies, such as studies of the space-time structure and variability of specific water masses. The DDB contains the current facts known about the area under investigation at the time, plus a model of the area which describes (suspected) events, boundaries, etc., and information on the evolution of dynamic processes. The expert system contains the "inference engine" to apply inference rules (from the SDB) to information in the DDB; the results of the application of the rules are new facts in the DDB. In the initial system there will be no direct connection between the image processing work station and the expert system. Later phases are envisioned as beginning to couple the two.

The initial system will provide a prototype for experimentation and development of techniques. The experimentation will reveal flaws in the initial set of inference rules, and will help in the organization of knowledge in the form useful for this kind of system. The acquisition of new knowledge in oceanographic image interpretation and experience in the use of the system will make it possible to enhance the prototype. By a "bootstrapping" approach, it will be possible to develop a more refined, more sophisticated expert system. That later system should make possible more automated, less interactive image/sensor data processing. The development of this prototype system will accomplish some of the goals set forth earlier in this paper.

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Developments in Satellite Technology for Oceanic Operations

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ABSTRACT

From March 1985 through 1995, twenty new oceanic satellite sensors are planned for launch on eight satellites. Of this ensemble of sensors, the oceanic scientific and operations communities will have access to, through the National Oceanic and Atmospheric Administration, a major increase in the prime ocean parameters of surface winds, temperature, waves, color-derived characteristics, circulation, currents, sea ice and ice sheets, and geodetic information.

The majority of satellites are non-NOAA and are to be launched by other U.S. federal agencies or foreign space agencies. The exception is the possible flight of an ocean color instrument on a NOAA satellite in early 1990.

Presently, ship and buoy sources for surface winds, temperature, and waves provide two to four thousand reports per day globally, and the satellite-derived sea surface temperatures provide 30 to 70 thousand sea surface temperature retrievals per day. With the planned satellites and sensors, the ensemble, of ocean data will increase from four to five million retrievals per day. This increase will offer the opportunity for governmental, academic, and commercial engineers in oceanic development programs to expand the near real- time and retrospective data bases that are global in extent.

Along with developments in satellite technology for oceanic operations, this paper also outlines the plans currently being evaluated for oceanic space sensors from 1995 to 2000.

INTRODUCTION

Satellite observations of the ocean surface and near surface are on the threshold of major advances during the next 10 to 15 years because of advances in space technology made during the past 10 to 15 years. The technology has been demonstrated through National Aeronautics and Space Administration (NASA) programs such as the Nimbus series of satellites, and special dedicated satellite systems, including the Geodynamics Experimental Ocean Satellite (GEOS-3) launched 9 April 1975, and Seasat launched 26 June 1978. These satellites and sensors have established the dynamics of the ocean surface (upper tens of meters) and the strong coupling at the planetary boundary layer between the ocean and the atmosphere.

It is important to recognize the role and responsibilities of NASA as distinct from those of the National Oceanic and Atmospheric Administration (NOAA). NASA leads the world in the development of satellite earth-observation techniques for science and operations. All NOAA oceanic operational capability in satellite remote sensing is directly traceable to NASA programs. But science and earth observations cover much broader activities and are of far greater significance than that permitted by the occasional research satellite observations provided by NASA. Once the technology has been demonstrated by NASA research, the strength satellites bring to marine science and operations is the systematic observation of the oceans via continuing measurements. Such measurements are provided by NOAA operational systems or obtained by NOAA from other satellite systems, both national and international.

This paper will focus on the highest priority physical and biological features required for oceanic observations. These include winds, waves, sea surface temperature, sea ice, currents and circulation, and ocean color derived products. Quantitative comparisons will be made only for winds, waves, and temperature.

MARINE DATA STATUS

Systematic marine observation using satellite techniques are evolving in a manner similar to those that now provide weather and meteorological information. NOAA has assembled requirements for the civil oceanic community that involve both scientific and operational needs.[1,2] Securing access to these data by the U.S. civil marine community is considered the highest priority activity for the marine-related responsibilities of the National Environmental Satellite, Data, and Information Service (NESDIS).[3] The mechanism proposed by NESDIS is one which involves the use of many planned and proposed satellite systems by both the United States and other nations.[4] The collective capability of these planned systems exceeds the global coverage that anyone agency might provide within a single space program. The union of these systems offers advantages to all mariners and this potential union is the main theme of this paper.

The present state-of-the-art of satellite measurements of ocean parameters based on generic types of sensors is shown in Table 1. It must be underscored that this capa-

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Table 1. General Summary of Oceanic Sensor Results[a]

Parameter	Altimeter	Scatterometer	Multichannel Radiometer: Microwave	Multichannel Radiometer: Infrared	Synthetic Aperture Radar	Ocean Color Instrument
Altitude	8 cm (prec.)					
Geodesy						
Mean Sea Surface	70 cm (prec.)					
Winds						
Speed	2 m/s	1.3 m/s	2 m/s		Detected	
Direction	—	16"	—		—	
Waves						
H1/3	0.5 m or 10%					
Wavelength					12%	
Wave Direction					15°	
Internal					Monitored	
Sea Surface Temperature			1°C	0.6°C		
Sea Ice						
Location			20 km	7 km	os km	
Type			1st yr. vs. mult-yr.			
Edge	Detected	Detected	20 km	7 km	os km	
Ice Sheet						
Height	1.6 m (prec.)					
Ocean Color						
Pigments						30%
Dif. Att. Coef.						40%
Water Mass Det.						1-2 km
Circulation						
Cur. Bound.	Detected-8 km		1-2 km		Detected	1-2 km
Currents	Variable (lat. Depend,)					
Eddies	Detected-1 Ocm level		Warm Eddies		Detected	Detected

[a]Unless otherwise noted, the values are the accuracies compared to *in situ* sources; where a % and a number are given, whichever is greater applies. N.Q. indicat es not qualified; detected means the feature was observed but did not lend itself to quantification with surface truth.

bility is the result of NASA research using the Seasat, Nimbus-7, and TIROS-N satellites. NOAA investigators participated in each of these systems to assess the oceanic satellite capability for future operational systems.

Different sensors have differing capabilities, in some cases, to make the same measurement. For example, sea surface temperature can be measured to an accuracy of about 0.6°C using infrared sensors, but only to about I. 0°C using microwave instruments. The infrared measurement will be limited by atmospheric conditions in-eluding cloud cover, but the microwave sensor will be near all-weather in providing sea surface temperature observations.

The current sources of satellite data for operational applications are, derived horn the two NOAA satellite systems shown m Figure 1. The Advanced Very High Resolution Radiometer (AVHRR) is the principal quantitative data sensor and provides the sea surface temperature data cited in Table 1 for infrared radiometers. The Navy's Geosat system is presently operating Lawlessly and it is anticipated that the data will be available to the civil community by August 1986. Geosat will be discussed subsequently. The Geostationary Operational Environmental Satellite (GOES) serves the oceanic corn. munity particularly well in providing *severe* storm warnings and nowcasts, but is principally a qualitative instrument for marine observations. The Search and Rescue and the Data Collection Systems provide important services to the oceanic community, but will not be considered here in order to emphasize satellite remote sensing techniques. These latter two services are expected to be maintained over the next decade at the current or improved levels of capability subject to continuing the current operational satellite system which uses two polar and two geostationary satellites.

The satellite capability outlined in Figure 1 is planned to be expanded using other agencies and nations satellite systems. In particular, the system will *grow* over the next five to six years so that the decade of the 199fY5 will begin with an ensemble of satellites that, for the first time, will meet requirements for many users. These users include bath research and operational mariners. The sequence of growth is shown in Figures 2 through 5.

PLANNED SATELLITE SYSTEMS

The U.S. Navy and Air Force and the European Space Agency (ESA) have planned satellite systems and sensors that will be responsible for a revolution in oceanic data availability. NOAA expects to initiate a companion program 10 provide these data to U.S. marine users. The key systems to the companion program are outlined below, Most important for all users, including government, industry, and academia, is that only modest resources (compared to the already committed space resources) are required to bring the companion program to a reality.

Geosat

Geosat was launched on 8 March 1985 with an expected lifetime of three years. It is an altimeter-only, polar-orbiting satellite whose altimetric frequency of op. eration is at 13.5 Ghz with a range precision of 3.5 cm. This precision will be about twice that of the Seasat altimeter. The orbit will be very similar to that of Seasat; viz., an altitude of 800 km at an inclination of 108°. The Applied Physics Laboratory of The Johns Hopkins University and the Naval *Ocean* Research and Development Activity on behalf of the U.S. Navy are responsible for this mission.

The mission of Geosat is twofold: first to provide for improvements in gravitational models of the Earth; and second to provide oceanic data on surface windspeed, significant waveheight, sea ice edge and roughness, ocean fronts, and detection of mesoscale oceanic features. Data from the geodetic-related mission will not be available directly to the civil marine community during the first 18 months while the orbit is in about a 72-day repeat cycle, This cycle will provide about a 40-km grid at the equator, with six complete cycles expected during the first 18 months. The second 18-month period will use a repeat cycle of 20 days, which will provide an equatorial grid of about 140-150 km. During most of the mission, environmental data will be available to all civil marine users through NOAA participation,

In summary, the altimeter provides three basic signals related to the measurement of the following oceanic information:

- Surface windspeed—±1.8 m/s from I-18 m/s,
- Significant waveheight (H ⅓)—Within 10% or ±0.5 m, whichever is larger,
- Mesoscale oceanic features- ±3.5 cm in range for 2 m H⅓, and
- Sea ice-water edge—Yes/no to within 8 km.

Special Sensor Microwave Imager (SSM/1)

The Defense Meteorological Satellite Program (DMSP) will launch in mid-1986, the Special Sensor Microwave Imager (SSM/I) as a joint activity between the U.S. Navy and Air Force (see Figure 2). The SSM/I is a seven-channel, four-frequency instrument with frequencies of 19.3,22.2,37,0, and 85.S GHz and an effective field-of-viewof70 x 45,60 x 40,38 x 30, and 16 X 14 km,

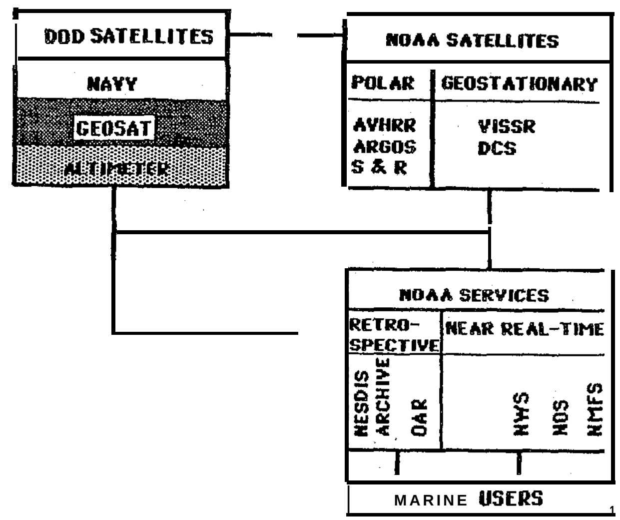

Figure 1. *The 1985 Operational Satellite Oceanic Remote Sensing Information Collection System.*

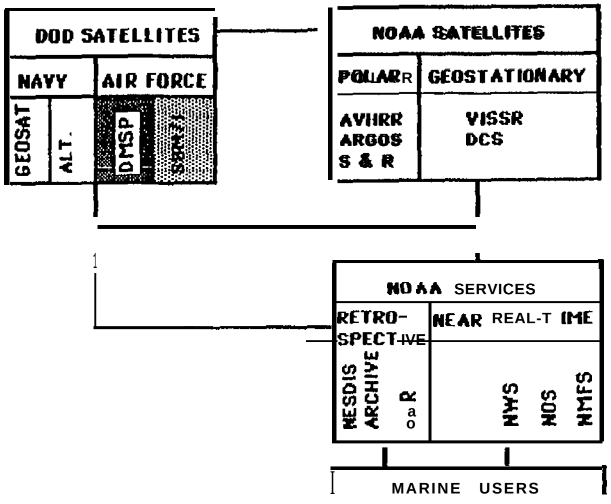

Figure 2. *The 1986 Operational Satellite Oceanic Remote Sensing Information Collection System.*

respectively. Dual polarization is at all frequencies except 22.2 GHz.

The desired spatial resolution of 25 km is the goal for the following SSM/I parameters:

- Surface windspeed—± 2 m/s over the range 3–25 m/s
- Sea ice cover—± 12% over 0-100%
- Sea ice age—1st year versus multi-year ice
- Sea ice edge .t12. shill
- Precipitation ± 5 mm/hr. over the range 0-25 mm/hr
- Cloud vapor ± 0.1 kg/m² over the range 0-1 kg/m²
- Liquid water , 2.0 kg/m² over the range 0-6 kg/m²
- Soil moisture—Dry-moist, wet-saturated.

Shared Processing System

A new element of major support to providing data to the oceanic community is a communications link among the principal Navy, Air Force, and NOAA environmental data processing centers. In mid-1987 the installation of a real-time communications link interconnecting the Fleet Numerical Oceanography Center (FNOC), Air Force Global Weather Central (AFGWC), and NOAA's facilities including the National Weather Service (NWS), the National Ocean Service (NOS), and the Navy/NOAA Joint Ice Center will be established. Figure 3 illustrates the expanded capability to access data in near real-time. Users with the proper ground systems can receive processed data at the same time as the Navy, Air Force and NOAA receive data. The data flow diagrams in this figure and Figures 4 and 5 are programmatic to show end-points for data availability.

The Shared Processing System is a cooperative agreement. FNOC will provide analyses of oceanic data; AFGWC will process and map visible and infrared imagery; NOAA will be responsible for the processing of atmospheric sounding data. All centers will exchange their products via a domestic communications satellite link called the Shared Processing System and the system will carry environmental geophysical data located in both time and space. NOAA will also be responsible for providing the environmental data archive for all Shared Processing System data. This system is a vital ingredient to the distribution of all satellite data that will make a major advance possible in the availability of data to the marine community. The data residing in the Shared Processing System will include the satellite geophysical data located in time and space.

NOAA-Net and NOAA-Port

In order to improve the data availability to all environmental data users, NOAA has proposed the NOAA Data Access System (DAS) which is composed of two major elements. (DAS is only proposed at this time. All satellite systems discussed in this paper are funded programs unless noted otherwise.) First, a near real-time operational data delivery system (NOAA-Port), and second, a retrospective data management and user services system (NOAA-Net). The overall system, as proposed, wdl provide the following capabilities:

1. Computer processing/communications capacity to collect operational environmental data, format these data, and schedule for delivery to the NOAA-Port data transmission facility.

   Wideband digital data broadcast system for delivery of near real-time environmental data and products to the NOAA user community.

3. Modification of the Satellite Weather Information System to handle digital data, and installation of display systems for use in National Weather Service field stations.
4. Establishment of a permanent mechanism to determine which data should be acquired for long-term retention in NOAA's national environmental data base, and how long these data should be retained in the data base.
5. Upgraded system capability to handle rapidly mere.wing retrospective data volumes through the use of state-of-the-art processor capacity, high density optical storage, communications, and improved software applications.
6. Improved data and information delivery capability to provide retrospective data users with turnaround time measured in minutes and hours rather than the current longer times.
7. Technology to link NOAA's data base to other national and international data bases to provide retrospective data users with access to all available data, thereby providing a mechanism for interactive multidisciplinary applications.
8. Improvements to the present retrospective data holdings necessary to generate Ckm.it;, information and support climate analyses and assessments. The mechanism established will be carried forward to *support* long-term marine problems involving ocean flux, transport mechanisms, global-scale anomalies, etc.

It is expected that the NOAA-Port and NOAA-Net concept wdl initially start in 1988 as *drown m* Figure 4. The Shared Processing System will be a major element in the NOAA-Port element of DAS for marine users, and NOAA-Net should provide access to retrospective data in timeframes comparable to speed of delivery of data in the Shared Processing System.

ESA Remote Sensing Satellite (ERS-1)

The European Space Agency (ESA) Program for oceanic satellites is focused on a 1989 launch of the first ESA Remote-Sensing Satellite (ERS-1) as illustrated in

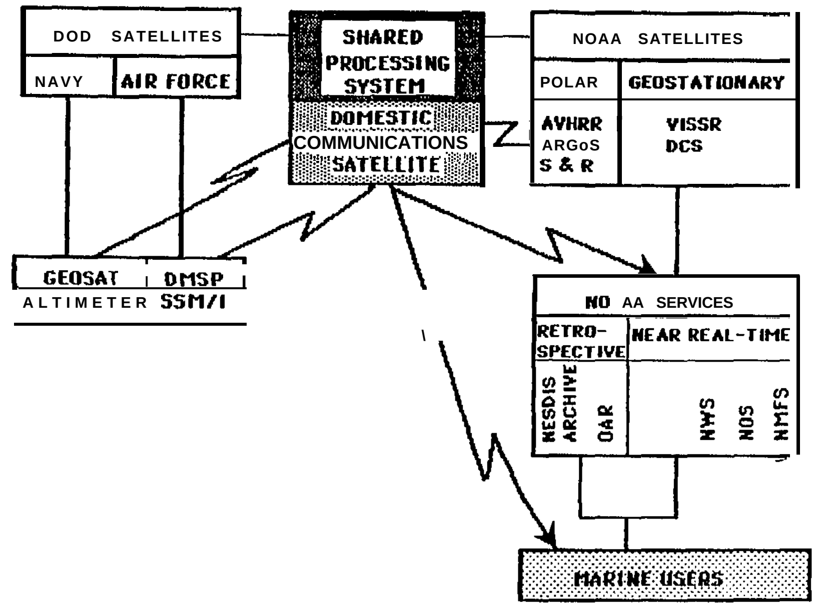

Figure 3. *The 1987 Operational Satellite Oceanic Remote Sensing Information Collection System.*

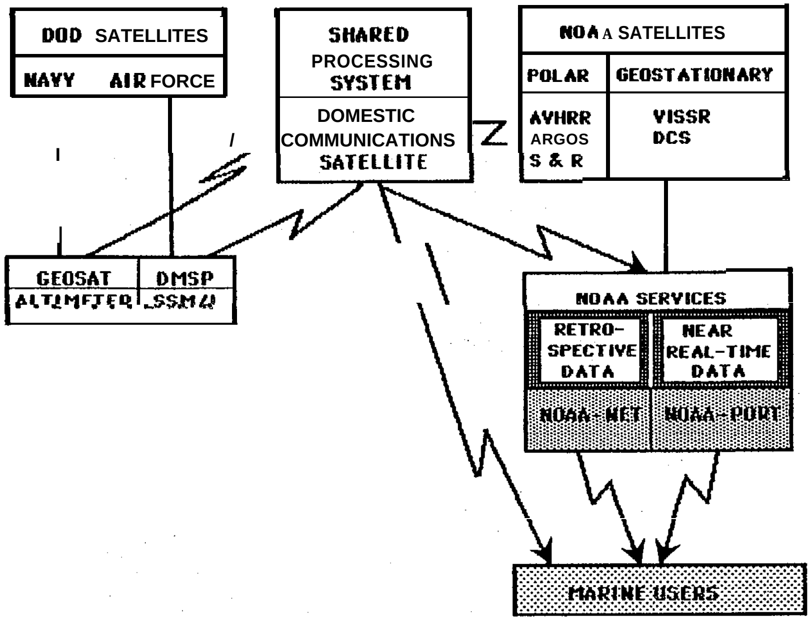

Figure 4. *The 1988 Operational Satellite Oceanic Remote Sensing information Collection System.*

Figure 5. The nominal orbital characteristics of ERS-1 are a 777-km altitude, sun-synchronous, circular *orbit* with a local equatorial crossing time of 10:15 a.m. The baseline orbit will have a 3-day repeat cycle and will use a 98.52° inclination with 14.333 orbits per day.

The primary mission of ERS-1 is to increase scientific understanding of global ocean processes, and promote economic and commercial applications. This mission is to be accomplished by a payload consisting of an Active Microwave Instrument (AMO, a radar altimeter, andan infrared Along-Track Scanning Radiometer (ATSR). In addition, a Precise Range And Range-Rate Experiment (PRARE) is being studied to expand the ERS-1 mission to include geodetic and geodynamic applications. Because PRARE will not make environmental measurements, and is considered to be a very ambitious undertaking which may not be included in the final payload, it will not be considered here.

The Active Microwave Instrument (AMI) is an alternative approach to separate instruments Oown on Seasat. It is composed of two separate C-band systems which operate in three distinct modes that include Synthetic Aperture Radar (SAR), wave spectrometer, and wind scatterometer.

In the SAR mode, data are collected over a swathwidth of at least 80 km with a spatial resolution of 30m. The data rate, as with Seasat, is very high and will not be collected on-board the spacecraft. Direct transmission will be to SAR read-out stations at Kiruna, Sweden, and possibly other sites including a NASA-sponsored station a: Fairbanks, Alaska. NOAA expects to process the SAR data collected by the NASA receiving station in Alaska in near real-time for use by Arctic region industry and research. The general AMI-SAR mode parameters inelude those listed above and a frequency of 5.3 GHz, incidence angle of 23°, requiring 300 watts of average transmitted power from an antenna measuring 10 m x l m. The anticipated data rate is 100 Mbit/s.

The SAR data, depending on the location of other read-out stations, will be used for a number of studies, experiments, and operational applications. Sea ice monitoring will be a key requirement for these Arctic observations. Internal waves, mesoscale and microscale eddies, bathymetry, waves in severe storms, currents, oil spills, and ship wakes will be other potential SAR observations. The ERS-1 SAR data will be similar to that of Seasat except for the differences caused by the higher ERS-1 SAR frequency. This may produce a substantial difference in some applications.

When in the wave spectrometer mode, the ocean surface will be sampled ina 5km² area every 100 km along the ground track. This permits the sampling of wave conditions intermittently to measure wavelengths from 50 to 1000 m to within 20% over 0-360° in direction (to within 15"). This mode of operation will be time. shared with the wind scatterometer mode.

The AMI wind scatterometer mode will perform in a manner very similar to Seasat except the sensor looks only to the right side of the spacecraft track and operates at the C-band (5.3 GHz) frequency as compared to the 14.5 GHz of Seasat. The swathwidth is 500 km located between 250 to 750 km to the starboard side of the spacecraft track. The sampling spacing is 25 km with a spatial resolution of 50 km across the swathwidth. Wind speed determination is ± 2 m/s or 10%, whichever is larger, over the range of 4 to 24 m/s. Wind direction is ± 20° over the interval of 0-360°, and uses three beams oriented at + 45", O", and – 45°.

The ERS-1 altimeter is similar *to* other Ku-band altimeters and will have the same general characteristics as Seasat. The range precision will be 10 cm, and is expected to determine Hi/3 to ±0.5 m or 10%, whichever is larger over the range of 1 to 20 m.

The Along-Track Scanning Radiometer (ATSR) is designed to provide an absolute sea surface temperature accuracy of better than ±0.5°C with a spatial resolution of 50 km in conditions of up to 80% cloud cover. The actual spatial resolution of the instrument is 1 km and uses three channels at 3.7, 11.0, and 12.0 m. The conical scanning system observes the ocean surface at two angles of incidence in order to improve the current state-of-the-art for SST observations. Al the subsatellite track these angles of incidence are at 0° and 57". The swathwidth is 500 km. A passive microwave system, which looks *only* at nadir, is also included in the ATSR and is designated as the ATSR-M. It will be used to make atmospheric corrections for the altimeter.

Navy Remote Ocean Sensing System (N-ROSS)

The Navy Remote Ocean Sensing System (N-ROSS) is to be launched in the mid-1990 period. The orbit is to be sun-synchronous at an altitude of ≈833 km with an inclination of 98. 7° and a possible 0530 descending local equatorial crossing time. Approximately 14.22 orbits/day give N-ROSS a repeat cycle of approximately every four days.

The primary mission of N-ROSS is to provide all-weather, global oceanic data to support numerous fleet activities. However, while many of the data products will be unique to Navy needs, the basic data set will be *composed* of geophysical information needed by [he civil, oceanic, scientific, and operational communities. The Navy expects 10 make the basic data available to the civil community through the NOAA system, assuming

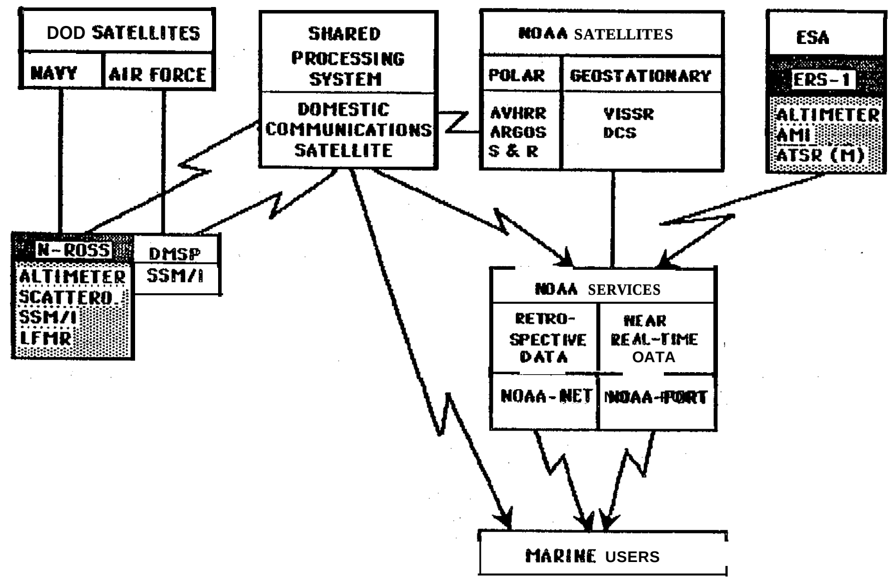

Figure 5. *The 1989-90 Operational Satellite Oceanic Remote Sensing Information Collection System.*

that the data system can be improved to handle the significant increase in the satellite data anticipated. Except for ocean color, the N-ROSS capabilities will be equivalent to those of the proposed National Oceanic Satellite System (NOSS) that was considered in the early 1980's. The all-microwave sensors consist of an altimeter identical to the one on Geosat, a Special Sensor Microwave Imager (SSM/I) identical to the instrument in the DMSP system, a scatterometer provided by NASA and designated as NSCAT, and a Low-Frequency Microwave Radiometer (LFMR). Only the last two sensors are discussed as the first two have been considered earlier.

The most significant improvement in the scatterometer over Seasat is the use of a three-beam system and a slightly larger swathwidth. The three beams will reduce wind alias values by a factor of two. The swathwidth will be about 20%, greater covering a region extending from about 150 to 750 km on each side of the spacecraft, yielding a 1500 km swathwidth with a 300 km gap centered below the satellite track. The key characteristics are:

- An operating frequency of 13.995 GHz
- A wind vector spatial resolution of 50 km, while the radar backscattering cross-section will be processed at 25 km
- A wind speed resolution of ±1.3m/s over the range of 4-26 m/s
- A wind direction resolution of ±16° over the range of 10".3(,0".

The Low-Frequency Microwave Radiometer (LFMR) is a dual-frequency and polarization radiometer designed specifically for the near all-weather measurement of sea surface temperature. It is a new design with a heritage similar to the large radiometer system proposed for the previously mentioned NOSS facility. The baseline characteristics of this conically scanned, 5.9-m antenna radiometer are:

1. Frequencies of 5.2 and 10.4 GHz
2. An angle of incidence of 53.1°
3. An effective field-of-view of 15 x 25 and 8 × 13 km at the lower and higher frequencies, respectively
4. A total swathwidth of 1400 km.

The goal for the derived sea surface temperature accuracy is ±0.5°C at a surface resolution of 10 *km* with ±1()"C and 25 km surface resolution considered acceptable.

An important element for operational oceanic data is the merging of data from N-ROSS and ERS-1. The combined system will provide global wind data every 24 hours, an important consideration in the forecast of marine weather. NOAA proposes to serve the U.S. marine community as the data gateway between these two systems when they are both operating simultaneously in the 1990 time period.

Other Sensor Opportunities

There are other satellite systems that are planned for the early 1990's. These systems include the Canadian Radarsat System, the NASA Topography Experiment (TOPEX), the NASA Geopotential Research Mission (GRM), and a possible continuation of the Nimbus-7 Coastal Zone Color Scanner (CZCS) program with a NOAA or industry Ocean Color Instrument (OCI) that would be flown on the afternoon polar-orbiting satellite in the NOAA K,L,M series (See also Table 3).

The proposed OCI system is the only remaining sensor not planned for space flight that has been demonstrated to have major research and operational applications.[5,6] The possible use of an ocean color sensor is being given serious attention as an instrument to be continued by private industry.[7]

The technology for determining chlorophyll concentration, diffuse attenuation coefficient (turbidity), water mass boundaries and fronts, open-ocean upwelling areas, and estimates of productivity has been established by NASA and the ocean research community during the highly successful CZCS mission which has been in progress since Nimbus-7 was launched in October, 1978. The technology demonstrated through CZCS data shows significant utility for physical oceanography and dynamics, as well as the originally anticipated applications to biological oceanography.

The Polar Platform/Space Station Connection

By the mid-1990's, a space-station supported polar orbiting satellite concept may provide a major change in the manner by which data continuity is assured to both research and operational marine activities as well as to users of Earth environmental data. In principle, such a space station facility would be attended by professionals to maintain the system as required and to up-grade capabilities as new technology permitted.

The basic concept is founded on the following working assumptions[8]:

1. Two platforms are necessary to meet earth-observation requirements similar to the existing NOAA series of polar satellites.
2. One platform (the morning platform) will be provided by another country or agency—e.g., the European Space Agency (ESA).
3. Both platforms will carry an international mixture of instruments provided by many countries and serving several disciplines in the earth sciences and operations.
4. The platforms will be serviced by an international astronaut crew.
5. The mission and payload control centers for the platforms will be internationally staffed, even if it proves necessary or desirable to maintain two sets of such centers (with extensive interconnecting communications links), one in the United States and one elsewhere.
6. Nations, both participating and nonparticipating, will require a variety of direct readout services even with the full deployment of the Tracking and Data Relay Satellite System (TDRSS) by the United States and other satellite data relay systems, such as that under consideration in Europe.

The payload of the polar-platform concept consists of four sensing assemblies: atmospheric and meteorological, solar-terrestrial environment, oceanic and solid earth. It also consists of two specialized instruments, one for data collection and platform location and a second for satellite-aided search and rescue. The Oceanic Remote Sensory Assembly (ORSA) is envisioned to be composed of an ensemble of sensors to make the following measurements: sea surface temperature, sea surface winds and waves, significant wave height and possibly wave spectra, currents and circulation, sea ice, biological productivity, and coastal/estuarine sediments and pollutants. These sensors will put on an operational basis the capabilities demonstrated by the research, development, and demonstration programs conducted during the late 1970's and throughout the 1980's.

In essence, before the year 2000, there appears to be an opportunity for significant change in the manner by which operational sea data are obtained. The polar-orbiting, man-tended observing system will have a high probability of being maintained over several generations—the exact ingredient needed to supply data to all oceanic users. This *opportunity* has led to the establishment of a special project designated as the Envirosat-2000 Project. More than a dozen special studies have been conducted to date with the summary, "The Envirosat-2000 Plan," scheduled for publication in the near future.[9]

THE ANTICIPATED DATA LEVELS

The evolution of satellites over the next five to six years from that shown in Figure 1 will result in an expansion of capability as shown in Figure 5. By the 1989-90 period, the Geosat system may well have been terminated after a successful three-year mission. Three SSM/I systems may be operational during this time. Considering the present day system, which provides 2-4 thousand ship reports a day, coupled with 30 712 thousand sea surface temperature retrievals from satellites, the data are anticipated to grow to the levels shown in Table 2. This table quantifies the *wind*, temperature, and wave data levels for global coverage. Three orders of magnitude increases are potentially available to support marine users.

Table 2. Anticipated Levels of Oceanic Data (Ships and Buoys, NOAA-Series, Geosat, DMSP, N-ROSS, ERS-1)

	Data Reports Per Day in Thousands					
	1984	*mid-1985*	*1986*	*1987*	*1988*	*1989*
Winds						
Speed	2-4	60	1,000	2,000	2,000	4,000
Direction	2-4	2-4	2-4	2-4	2-4	400-910
Sea Surface Temp.	30-70	30 70	30-70	30-70	30-70	650
Waves	2-4	60	[illegible]	60	60	120

Such increases will improve marine weather forecasts and permit the distribution of new products and applications by the value-added industry. This virtual data explosion will create a formidable requirement and opportunity for data management, both near real-time and retrospective.

To effectively use these data, a partnership involving all classes of user groups (government, private, academic, non-profit, social, recreational, environmental, research, operational, etc.) will be required to form a coalition of civil oceanic users to insure the availability of these data to all segments of the community. No one element will be able to carry the entire responsibility, yet the modest costs required for each will more than justify the U.S. investment. Approximately one and a half billion dollars of ocean-observing hardware has already been committed for launch into polar orbit during the next six years. The cost to make these data available to all civil users will be more than an order of magnitude less than the space hardware investment already made by many agencies, both U.S. and foreign.

However, the story of satellite oceanography does not stop at this juncture. The national and international plans call for many *other* ocean-science/applications sensors to be launched during the next decade. The ones outlined above are already under hardware development. If those satellite systems under study and those with the capability to support specific types of ocean-related applications (i.e., Landsat techniques applied to estuarine and wetlands studies) the ensemble of sensors is further expanded. Table 3 illustrates the potential systems, some still in the definition stage, that will potentially operate over the next decade. By the 1994-95 period, most attention will probably focus on the polar platform concept associated with the NASA Space Station.

SUMMARY

NOAA's objective is to bring the planned future oceanic satellite data to an accessible point in an accept-

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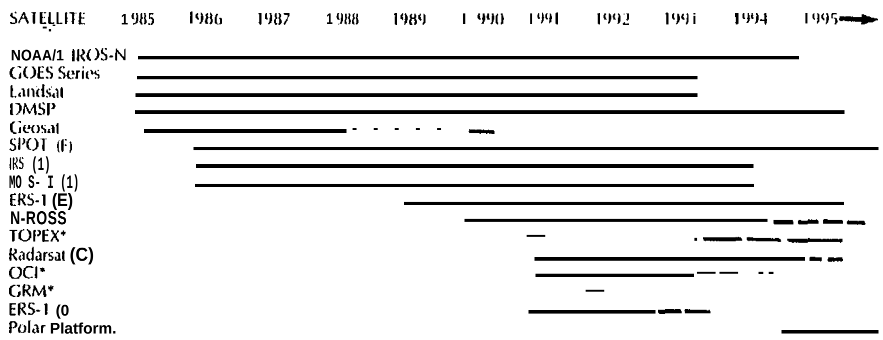
Table 3. Summary of Satellites During the Next Decade with Oceanic Remote Sensing Capability,"



'Heavy lines begin in 1985 for ongoing operational systems and at the approximate launch date for ail others. Legend: (C) Canada; (E) European Space Agency; (F) France; (1) India; (j) Japan; Blank-U.S. "Planned but as yet unfunded

able format and in a time period commensurate with practical applications. A data gateway will be formed for both near real-time and retrospective data. The acceptable format is likely to be what is customarily termed Level-n data (time tagged, earth located, geophysical units). It is expected that the value-added industry would accept the task of developing products from the Level-n data once assured that the data will be available on an operational basis. It appears to be an historical fact that great opportunities bring great challenges. The challenge for the oceanic community will not be the same as many of the challenges of the past—namely, working in harsh environmental conditions in remote areas—but in banding together as a cohesive unit to assimilate and understand the dynamics of the oceans.

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Nimbus-7 Coastal Zone Color Scanner: Ocean Color Applications

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ABSTRACT

The Nimbus-7 Coastal Zone Color Scanner instrument characteristics are briefly reviewed. The pertinent optical properties which influence the magnitude and spectral distribution of visible region light energy emerging from the sea and the general forms of empirically derived bio-optical relationships are discussed. Examples of the application of the CZCS atmospheric correction algorithm, as well as the derived products of phytoplankton pigment concentrations and diffuse spectral attenuation coefficients [490 nm) are presented. Potential operational product applications for the marine industry and the inherent value of linked-data sources are introduced.

INTRODUCTION

Biological oceanographers have long been fascinated by forces controlling marine productivity. The basis for life within the sea lies in the photosynthetic process which is conducted by microscopic marine phytoplankton. This photochemical process, which utilizes carbon dioxide, water, nutrients and light energy to drive the reaction, produces organic matter with oxygen as a by-product. These photosynthetic phytoplankton are the link between solar energy and the production of biological fuel sources upon which all higher levels of the marine food web must depend. A knowledge of the distribution and abundance of phytoplankton helps elucidate the processes of productivity in ocean waters.

The application of ocean color can be traced to ancient times when navigators used color change as one of the means to identify specific currents and water masses—knowledge gained only through experience and passed on, in many cases, as closely guarded secrets. For example, the Carthaginian Phoenicians had a major trade system in the Atlantic more than 2000 years ago, but the knowledge of their trade-routes disappeared along with their empire.[1] Quantification of ocean color most probably began in April, 1865, with the experimental work of P.A. Secchi and was extended by the efforts of Forel and Ule before the 1900's.[2] The experimental work of many pioneers led to theoretical descriptions of oceanic optics, with one of the first rigorous theoretical treatments provided by S.Q. Duntley and his colleagues in the 1950's and 60s,[3-5]

During the mid-1960's that attention was drawn to the possibility of using satellite remote sensing as a tool to measure ocean color and relate it to the amounts of photosynthetic pigments present in marine phytoplankton.[6] Subsequently in the 1970's it was demonstrated by Clarke, Ewing, and Lorenzen[4] (based on their aircraft measurements of upwelled spectral radiance and surface chlorophyll *a*) that the remote assessment of a living marine resource may be possible. The significance of such a measurement capability was furthered by the work of Smith and Baker;[8] Clark, Baker, and Strong;[9] and Gordon and Clark.[10] The work of Smith and Baker[8] showed that a high correlation existed between the diffuse attenuation coefficient and the surface chlorophyll *a* concentration as well as the total chlorophyll a concentration in the vertical column. Clark, Baker, and Strong[9] demonstrated the covariation of the upwelled spectral radiance distributions to the concentrations of total suspended particulate matter. Additionally, their work confirmed a high degree of correlation between suspended particulate matter and the phytoplankton pigments of chlorophyll *a* and its detrital counterpart phaeopigments. Gordon and Clark[10] provided an analytical scheme 'for atmospheric correction and the subsequent retrieval of the water-leaving radiances and phytoplankton pigment concentrations for a planned NASA ocean color instrument. This set the stage for the measurement of ocean color from satellite altitudes on a global scale.

The first and only sensor deployed in space and dedicated to the measurement of ocean color is the Coastal Zone Color Scanner (CZCS). This sensor began operation on 29 October 1978, five days after the launch of the Nimbus-7 satellite that carried the CZCS and seven other sensors into orbit about 955 km above the earth's surface. It repeats its ocean-coverage pattern about every six days. Originally, the primary use was anticipated to be in support of marine biological research with the ultimate operational beneficiary being the fishing industry. Over time, the number of users expanded when the types of information went well beyond the biological studies, and now both science and marine operations that require physical oceanic data are numbered among the beneficiaries.

THE COASTAL ZONE COLOR SCANNER

The CZCS was launched on the National Aeronautics and Space Administration (NASA) Nimbus-7 satellite to determine the feasibility of ocean color measurements from space. As a proof of concept mission, it had a

Coastal Zone Color Scanner Imagery In the Marginal Ice Zone

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ABSTRACT

Imagery from the Coastal Zone Color Scanner (CZCS) from two different high latitude locations was analyzed to determine the potential as well as the limitations of the CZCS for studying mesoscale physical and biological oceanographic processes in the Arctic and Antarctic. The investigation focused on the marginal ice zone, a complex and dynamic interface between the atmosphere and the ocean which supports extraordinary concentrations of biomass. Imagery processed at the ice edge in the Denmark Strait and in the Norton Sound area of the Eastern Bering Sea confirms the usefulness of the CZCS in assessing pigment distribution as well as the physical processes driving biological production at high latitudes. Despite constraints imposed by cloud cover and algorithm limitations, the imagery clearly showed ice edge blooms, eddy formation, circulation patterns, and water mass boundaries.

INTRODUCTION

Since it was first established that the CZCS could successfully estimate near surface pigment concentrations to within a factor of two,[1,2,3,4] through measurement of ocean color, the technique has been applied toward the study of a number of physical and biological phenomena in several geographic areas. Early observations that water color as viewed through the CZCS could be directly related to variations in phytoplankton distribution were made in the Gulf of Mexico by a variety of investigators.[2,5,6,7] In 1982, Gordon and others showed that the CZCS could be used to study the temporal and spatial nature of warm core Gulf Stream rings. Gordon *et al.*[4] found that CZCS—measured phytoplankton pigment concentrations in the Middle Atlantic Bight and Sargasso Sea waters and shipboard samples from the same area varied by only approximately 30%. Abbott and Zion,[9] and others have compared variability in temporal and spatial patterns observed by the CZCS with various physical forcing factors in the California Current. The California Current System has also been investigated by Laurs, Fiedler, and Montgomery[10] who applied the CZCS to fisheries investigations and by the West Coast Satellite Time Series Advisory Group.[11] Feldman, Clark and Halpern[12] examined the 1982-1983 El Nino Phenomenon in the Eastern Equatorial Pacific using the CZCS imagery.

These and other programs have clearly demonstrated that the CZCS can be used to study some of the many time and space problems of large-scale physical and biological oceanographic processes which are often difficult to address solely through shipboard investigations. The CZCS, therefore, is a tool which provides a means to estimate the biological production of large ocean areas through measuring changes in ocean color. These changes in color are, in fact, due to variations in the concentration of chlorophyll *a* and associated degradation products. The composition of the water influences absorption and scattering processes to produce the color of the solar radiation reflected from the upper layers of the ocean.[7,13] In all oceanic areas except regimes of coastal and river outflow, the main particulate constituent of the water is phytoplankton, the microscopic plants which form the base of the food chain. It is these organisms which carry out photosynthesis, and, therefore, contain the dominant photosynthetic pigments which strongly absorb light in the red and blue portions of the spectrum of visible light. Areas with heavy concentrations of the phytoplankton and associated pigments change the color of the water from the deep blue of clear open ocean water 10 varying shades of green depending upon relative concentrations of the phytoplankton pigments present.[7]

The ability to measure through remote sensing the large and small scale variations in the temporal and spatial distribution of phytoplankton, is particularly valuable in the relatively remote areas of the world such as the polar regions where shipboard sampling is often severely constrained by extreme weather, ice, and general inaccessibility. Since the phytoplankton support, directly or indirectly, all higher trophic levels in the oceans, an improved quantitative understanding of population dynamics is critical to the study of a variety of important biological phenomena such as fisheries, El Nino events, global carbon budgets, ice edge productivity, recruitment mechanisms, and pollution occurrences.[7,13,14] Furthermore, phytoplankton distribution patterns have proven valuable in the synoptic study of mesoscale physical processes such as eddy formation and development, areal partitioning, upwelling, water mass distribution and current dynamics.

The CZCS has not been fully explored as a means to examine such physical and biological phenomena at high latitudes and, in particular, along marginal ice zone areas for two main reasons. In the first place, the spectral bands in the CZCS radiometer for discrimination of ocean color are located within the visible region of the electromagnetic spectrum and, therefore, require a cloud-free area of ocean from which to receive the backscattered radiance signal. Unfortunately, at high latitudes, and particularly, at the ice edge, areas of interest may be covered by clouds or fog for weeks at a time. Secondly, there are serious limitations imposed on imagery collected at high latitudes by the existing algorithms which retrieve pigment concentrations from the backscattered radiances. Special problems encountered at high latitudes are primarily a function of low sun angle which results in low radiant energy input to the system and may cause significant error in the Rayleigh calculation in the atmospheric correction algorithm.

However, the importance of the polar regions and the marginal ice zones in understanding many global oceanographic processes has provided a special impetus to try to determine the potential as well as the limitations of high latitude ocean color imaging. This study has focused on the marginal ice zone, a unique system which, each year, advances and retreats across approximately 7% of the world's ocean.[15]

As described by Johannessen *et al.*,[17] the importance of the marginal ice zone itself may be viewed from two very different but interrelated perspectives. The first pertains to societal needs and the second is scientific. With increasing human activity in the Arctic, for example, there is no question that it will be necessary to improve the ability to predict ice conditions to insure safe passage of vessels involved in Arctic activities such as offshore oil and gas development, the transport of resources from the area, and the shipping of supplies to Arctic communities. Better prediction of the location and nature of the ice margin *will* enable an improved capability to harvest some of the richest fisheries in the world which are located close to the marginal ice zone in portions of both the Arctic and Antarctic.[17] There are interesting unknowns regarding potential shifts in the position of the ice edge as a result of significant environmental changes such as increased atmospheric dust, major fluxes in the CO_2 balance, and increased atmospheric pollution.[17] In addition, the physical processes at this complex interface control the nature and abundance of the rich and diverse ice-edge ecosystem. Since the higher trophic levels depend, directly or indirectly, on phytoplankton production, it is important to understand the interactions between the physical processes influencing the advance and retreat of the marginal ice zone and the biological productivity associated with the ice edge.

Therefore, a study was conducted in which a number of CZCS scenes with large cloud free areas were located and processed in both polar regions. At many locations it was possible to obtain clear images, comparable to those produced at mid and low latitudes, which showed both gradual changes in phytoplankton distribution as well as more sharply defined features such as fronts, eddies, and rings. This paper discusses the biological and physical oceanographic information provided by selected images in the Arctic and addresses the encouraging potential use of the CZCS type imagery at high latitudes.

METHODOLOGY

The Coastal Zone Color Scanner

The only instrument in orbit which was designed specifically to measure phytoplankton pigment concentrations through ocean color is the Coastal Zone Color Scanner (CZCS), launched in October 1978 on Nimbus-7. The Nimbus-7 is a sun-synchronous, polar-orbiting satellite located approximately 955 km above the earth, crossing the equator at approximately local noon.[2,9]

The CZCS is a multispectral radiometer with six co-registered and internally calibrated spectral bands. Four narrow bands (20nm) are in the visible wavelengths centered at 443, 520, 550, and 670 nm, chosen for optimum ability to discriminate between variations in phytoplankton pigment concentrations.[2,7,9,18] Band 5 (700 -800 nm) provides a means for distinguishing between land, clouds, and water; Band 6, a thermal infrared band (10.5 to 12.5 μm), for measurement of sea surface temperatures. The CZCS has a ground resolution (pixel size) of 825 m at nadir with each complete two minute nadir scene measuring approximately 770 km along the satellite track and 1600 km along the scan line. Interference by sun glint can be minimized by tilting the scan plane along the satellite track in 2 degree increments as much as plus or minus 20 degrees from nadir.[2,7,9]

Algorithms

In order to extract the near surface pigment concentration from the radiant energy data received by the CZCS, it has been necessary to correct for radiance backscattered from the atmosphere and water. Atmospheric scattering, which can account for over 80% of the satellite received radiance, can be removed through a correction algorithm developed by Gordon in 1978,[19] which corrects for scattering from the air (Rayleigh scattering) and scattering from particles suspended in the air (aerosol scattering).[2,9,19,21]

The near surface pigment concentrations are then computed from corrected water-leaving radiances by a second, bio-optical algorithm developed by Gordon and Clark and modified by Clark in 1981.[18] This bio-optical algorithm relates water-leaving spectral radiance ratios to the combined values of the photosynthetically active pigment, chlorophyll *a* and phaeopigment *a*, its associated degradation product. In addition, an adjustment was made to compensate for the upwelled radiance from vertically distributed chlorophyll *a* and phaeopigment *a* in the upper part of the water column.[18]

In the imagery generated from the CZCS observations, the computed pigments have been assigned colors, producing a color or encoded digital map of the distribution of phytoplankton pigments for concentrations ranging between 0 and 30 mg/m³. The color coding progresses from the blues to the reds as the concentrations increase.

THE MARGINAL ICE ZONE

The marginal ice zone is a unique environment because of its important role both as a habitat which supports extraordinary concentrations of biomass as well as a complex and dynamic interface between the atmosphere and the ocean. This seasonally changing ice zone spans approximately 7% of the world's ocean during the yearly advance and retreat of the ice edges, covering approximately 17 million km² in the Antarctic and 8 million km² in the Arctic.[16,21] Its importance as a habitat in polar regions is underscored by the enhanced standing stock and biological activity found at the ice edge. These higher trophic level populations, in turn, reflect the rich phytoplankton concentrations associated with the ice edge which, except for spring bloom conditions, can be 3-4 times higher than open ocean waters in both the Arctic and Antarctic.[21-24] These ice-associated phytoplankton blooms and under-ice algae provide a plentiful food source for the herbivores such as amphipods, copepods, euphausids, and cryopelagic fish as well as for the benthic communities below.[21,23,24] This abundant food supply at the ice edge is, in turn, readily available to the many birds and marine mammals which utilize the ice not only as a food source, but also for living space, shelter, transportation, isolation, reproduction, and sanitation.[21,25]

The physical processes which occur in the marginal ice zone are extremely complex and dynamic. The presence of the ice at the air-sea interface has a profound effect on the nature of these processes and can exert considerable influence on momentum transfer from the atmosphere, surface albedo, thermal insulation between the ocean and atmosphere, wave damping, water temperature, and salinity.[16] Energy exchanges at the ice edge control the seasonal movements of marginal ice zones some of which (Bering Sea, Baffin Bay, and the Southern Ocean) advance and retreat as much as 10° in latitude each year.[16,21] Others, like the ice edge west of Spitsbergen, remain relatively stationary.[26] The marginal ice zone is kept in a constant state of flux by the winds and currents and may travel tens of kilometers daily, resulting in large wind-driven salinity and heat fluxes.[16] The spatial configuration of the ice edge is largely controlled by prevailing winds and currents,[17,27] wave action,[24,28] and temperature of surrounding waters.[16,26] Changes in wind direction relative to the ice edge and the local currents effect the shape and orientation of the entire ice edge and cause upwelling, downwelling, divergences, eddies, jets and floe movement.[17,26] It is hoped that the ongoing and planned interdisciplinary studies will provide answers to the many unknowns about the complex physical processes at this key geophysical boundary and contribute, in turn, to an improved understanding of the associated biological processes.

A model of the seasonal progression of production in, under, and near the ice edge has been described by Niebauer and Alexander[21] (see figure 1). In mid winter, low solar radiation levels plus heavy snow and ice cover severely limit algal growth under the ice although *some* has been reported during the winter season.[29,32] Active epontic algal growth on the underside of the ice begins as light increases in the late winter and early spring and reaches a peak in late May.[22,29,31,32] During the maximum growth period of the ice algae in late winter, there does not appear to be very much production by the phytoplankton in the water under the ice.[24,35] Active grazing of the ice algae by juvenile fishes, copepods, polychaetes, amphipods and other species expedites the transfer of the algae into the water column below.[21,34] Smith and Nelson[24] noted that, later in the spring, epontic algae are released into the stable lens of meltwater and those species capable of growth in this environment develop rapidly, creating a bloom condition. In areas like the Chukchi and Bering Seas, where the ice edge retreats across significant distances, the decline of the epontic community probably corresponds with the disintegration of the ice itself.[16]

As the level of solar radiation rises, algal growth in the water under the ice and in the open water along the ice edge increases rapidly. The most significant production, however, takes place as the ice begins to break up, with the bloom reaching a maximum intensity within the broken ice pack itself as well as in the waters influenced by the melting ice.[21,22,24] There *are* still questions regarding the longevity of ice edge blooms but condition of the ice, stability of the water column, and nutrient levels are undoubtedly important. Sakshaug[32] has suggested that ice edge blooms may trail the receding ice edge, scavenging the nutrients in the surface waters as they move poleward to their minimum point of retreat. In areas of substantial ice edge migration such as the Bering Sea and the Southern Ocean, ice edge blooms appear to be relatively short-lived.[21,31,34] Conversely, in the marginal ice zone of the East Greenland Sea, which maintains a relatively permanent location in the vicinity of the Mohn Ridge, the bloom is thought to persist as long as sufficient light is present.[26]

The exact mechanisms which cause ice edge blooms to develop are driven by the physical dynamics of the complex ice edge environment and are still not yet fully understood. Some of the mechanisms which have been proposed are:

1. Stabilization of the water column. The highly stable layer of low salinity meltwater appears to help maintain the phytoplankton in the photic zone where they can take full advantage of the favorable conditions for growth and reproduction.[22,24,26,36]

2. Upwelling. Wind-driven upwelling at the ice edge, which brings increased nutrients to the surface and stimulates phytoplankton growth, has been both modelled[38,39,40] and observed in the Arctic.[7,40,41] The low concentrations of nutrients in Arctic waters are reflected in the low levels of primary productivity which characterize these waters during non-bloom periods.[22,26] In the Antarctic, *however,* nutrients are not considered 10 be an important limiting factor because nutrient levels are consistently high throughout the surface water.[24]

3. Epontic Algae. The abundant populations of epontic algae appear to provide a valuable inoculum to the spring blooms at the ice edge although the exact role of these algae in the succession of the ice edge populations is still under investigation.[21,24,26,33]

4. Mesoscale Eddies. Mesoscale eddies along the ice edge in East Greenland Sea have recently been found to be an important means for transport of nutrient rich water to the euphotic zone and for controlling the distribution of the entrained plankton populations.[26]

While some of these physical and biological interactions which develop and maintain the greatly enhanced populations of plankton at the ice edge are understood, it is clear that there are many complex questions which will remain unanswered until further research on the subject has been completed,

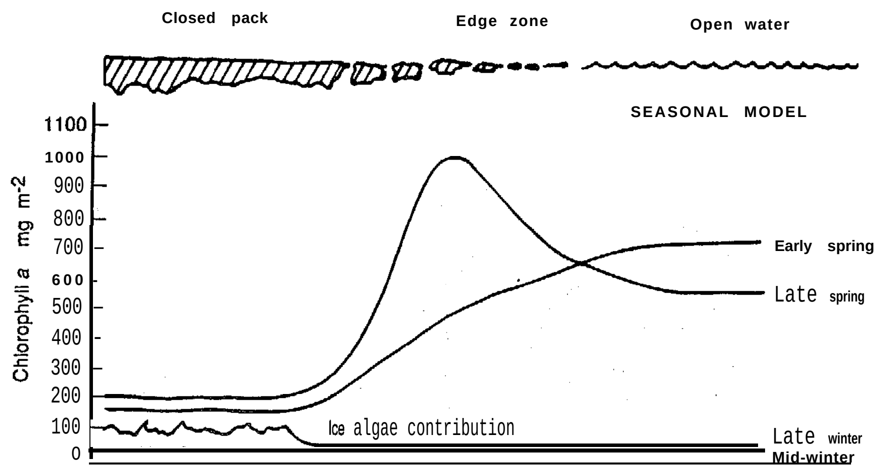

Figure 1. Conceptual model of the ice edge ecosystem in the Southeastern Bering Sea (Source: Niebauer and Alexander[21]).

IMAGERY FROM THE DENMARK STRAIT BETWEEN ICELAND AND GREENLAND

The first image to be processed along the marginal ice zone was in an area of the Denmark Strait between Iceland and Greenland on 9 April 1979. The specific area of interest is shown in Figure 2, an image from the U.S. Air Force Defense Meteorological Satellite Program (DMSP). The ice extends from Greenland northeast across the Denmark Strait close to the northwestern tip of Iceland. In an enlarged view of this area (Figure 3), using band 5 of the CZCS (750 rim), the melting ice can be seen mixed together with various sized floes along the ice edge between the open water and the first year ice. Figure 4, a CZCS image of the same area depicting the abundance of phytoplankton pigments, shows a well-defined region of greatly increased phytoplankton pigment concentration along this melting ice edge. The northern edge extends well into the ice pack with its highest values occurring close to the ice. The southern edge of the bloom is a cyclonic eddy-like feature with a tail of decreasing pigment concentration trailing to the south and east.

This feature appears to be an ice edge bloom responding to the seasonal increase of solar radiation, breakup of the melting ice pack, seeding by epontic algae, and increased nutrient supply. In (his case, nutrient enrichment may be due to the fact that this particular pad of the ice edge is located in an active area of interface between *two* major water masses (see Figure 5). Cold, low salinity water from the Arctic meets the warmer, more saline, and highly productive Atlantic waters carried north by a branch of the Gulf Stream.[43,44] The Irminger Current flows north as an extension of the North Atlantic Current, splitting into two branches west of Iceland. The western portion of the Irminger Current meets the East Greenland Current and flows south to form a cyclonic eddy in the Irminger Sea. The eddy formation shown in the CZCS image probably resulted from the influence of these converging currents and the interaction between prevailing winds and the ice edge, Smith *et al.*[26] recently reported the dramatic effect that wind and currents can have on eddy formation in the East Greenland Sea marginal *ice* zone, observing production of mesoscale eddies of nutrient rich water as a direct result of the juxtaposed warm and cold currents in the area.

The complexity of the currents around Iceland is further complicated by the north-south fluctuations of the boundary between Atlantic and Arctic waters from year to year.[41-44] As climatic conditions have changed over the years, the position of the t wo water masses has shifted

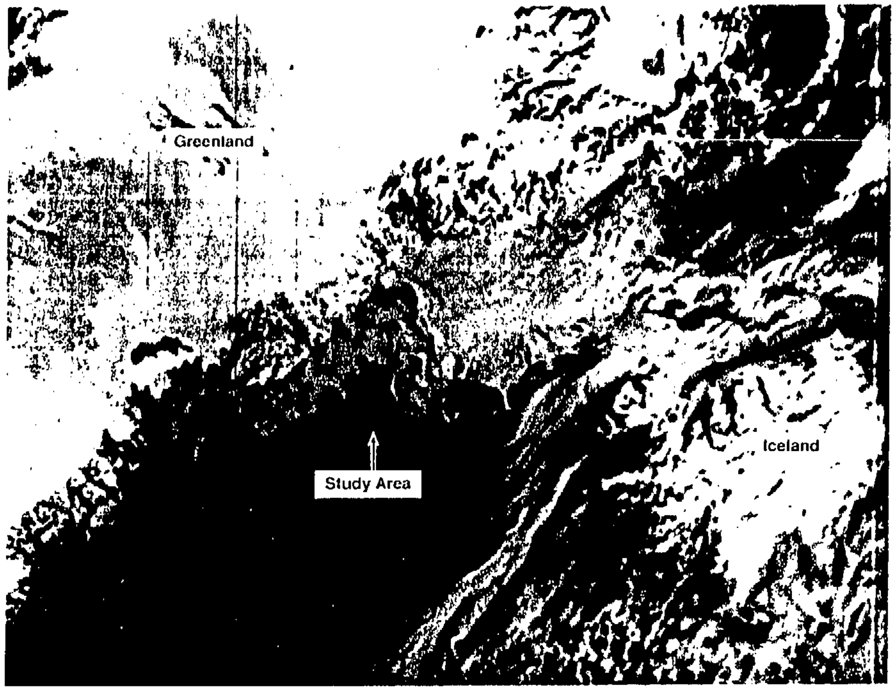

Figure 2. *DMSP image of the ice edge between Iceland and Greenland, 9 April 1979.*

accordingly. For example, colder years, accompanied by greater amounts of polar waters at the surface, are characterized by lower temperature and salinity at the surface and intermediate waters, an increased ice belt, and intensified stratification. These effects are far more pronounced in the northern Icelandic waters but some yearly shifts occur throughout the area.

Thordardottir has demonstrated that the productivity in those waters also changes according to the relative dominance of the Atlantic and Arctic waters and the increased stratification in the upper ocean. As stratification increases during the colder years, the active mixing of nutrients into the euphotic zone is inhibited and primary production is lowered. Similar changes take place at higher trophic levels which result in changes in the location of migration routes and spawning and feeding grounds of many commercial species.

Based upon estimates of Atlantic water input into northern Icelandic waters, 1979 has been classified as a cold year, which would suggest that overall primary production was lower than in warm years. Spring blooming in different areas around Iceland is variable but Thordardottir has shown that, in general, blooms occur somewhat earlier in Icelandic waters than in waters off the west coast. It is assumed with solar radiation intensifying at the end of March, that spring production could begin soon thereafter, or as late as the first week of June. Chlorophyll values measured in open ocean waters west of Iceland on 20 and 21 April 1979, were generally low, implying that blooming had not yet occurred in that region (unpublished data, Marine Station, Reykjavik). The CZCS image from the same general area (Figure 3) recorded very low values west of Iceland, with the ice edge bloom a dramatic contrast to ambient open ocean chlorophyll levels.

CZCS images such as the one presented here will help improve the understanding of the interactions of the physical and biological processes in Icelandic waters. While absolute chlorophyll values from the CZCS have yet to be verified in the analysis of the data due to potential problems with the algorithms, the patterns of pigment distribution provide significant mesoscale information on both spatial and temporal variations in watermass movement and biological productivity for this interesting and complex location.

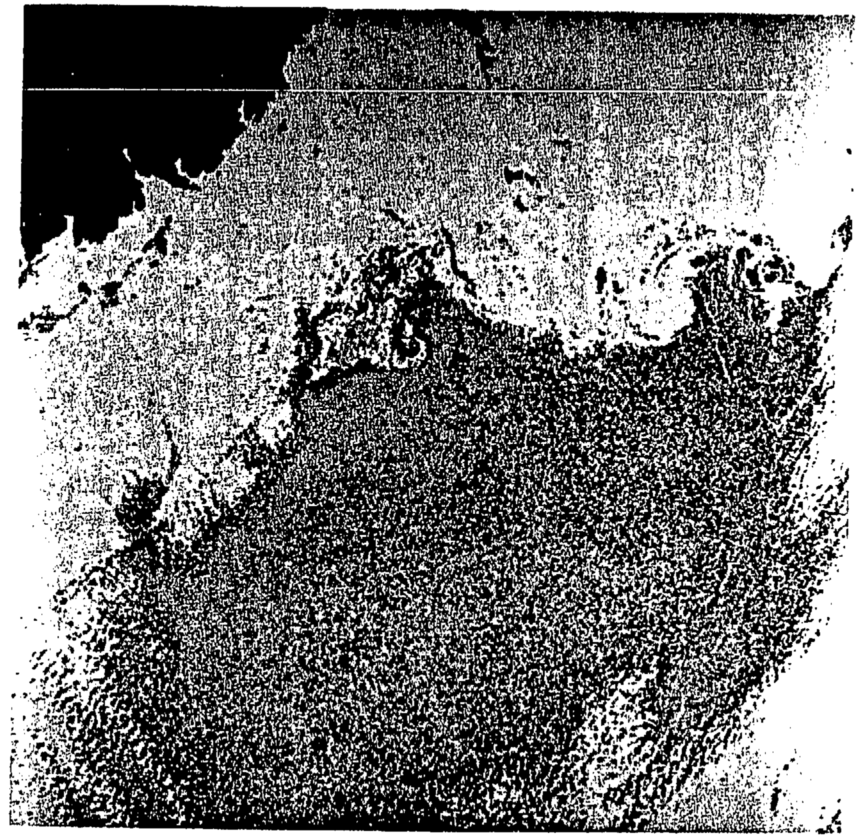

Figure 3. *CZCS image from band 5 (750 nm), showing details of the ice in the bloom area, 9 April 1979. (Courtesy of Dennis K. Clark, NOAA/NESDIS)*

IMAGERY FROM THE NORTON SOUND AREA OF THE EASTERN BERING SEA

An area from the Norton Sound of the Eastern Bering Sea (Figure 6) during the spring of 1979 was examined over a period of several months in order to gain a better understanding of the various ice edge mesoscale processes which take place during the annual spring retreat of the ice. A series of images were processed from early spring when the ice covers most of the region until summer when the Bering Sea is virtually ice free. Two images from that series which are presented here were taken 17 days apart in May of 1979. In corresponding DMSP images of the area (Figures 7 & 8), the pack ice can be seen rapidly melting and moving northward in response to southerly winds and strong northerly currents. In the earlier image, for example, the ice in the region north of St Lawrence Island appears to be actively melting, whereas, 17 days later that same section of ice appears to be moving North as more solid and well defined ice.

The pigment distribution in the CZCS images for the same dates (Figures 9 and 10) reflects the influence of the ice on phytoplankton growth and highlights several important physical oceanographic features of the Norton Sound area. The high pigment concentrations apparent on 12 May, west of the entrance to Norton Sound may be an example of the intense phytoplankton blooms associated with an actively retreating ice front. The ice edge in the Bering Sea shelf is known to be an area of intense surface blooms, particularly during breakup and retreat of the ice, and may account for a significant portion of the annual production of the Bering Shelf.[52,53] Significant levels of chlorophyll have been recorded within the broken ice pack as light becomes available to algae in a water column still stable due to the presence of the ice.[54]

Regions of ice slush are apparently particularly well suited for diatom growth and have been observed to produce very large blooms within a period of 24 hours.[54,55] On 12 May, the area of ice slush which can be seen on the DMSP image corresponds with the location of the blooms evident in the CZCS for the same day. Alexander and Cooney[54] have reported high chlorophyll levels ranging from 0-213.7 mg C/m^3 in the ice in this same area. By 29 May, the bloom appears to have disappeared along with any indication of actively melting or slushy ice. Only a few isolated areas of elevated pigment concentrations can be seen near the edge of the ice. The distribution of the pigments in the bloom outside

Figure 4. CZCS *false color image of ice edge bloom at the marginal ice zone between Iceland and Greenland, 9 April 1979 (Courtesy of Dennis K. Clark, NOAA/NESDIS).*

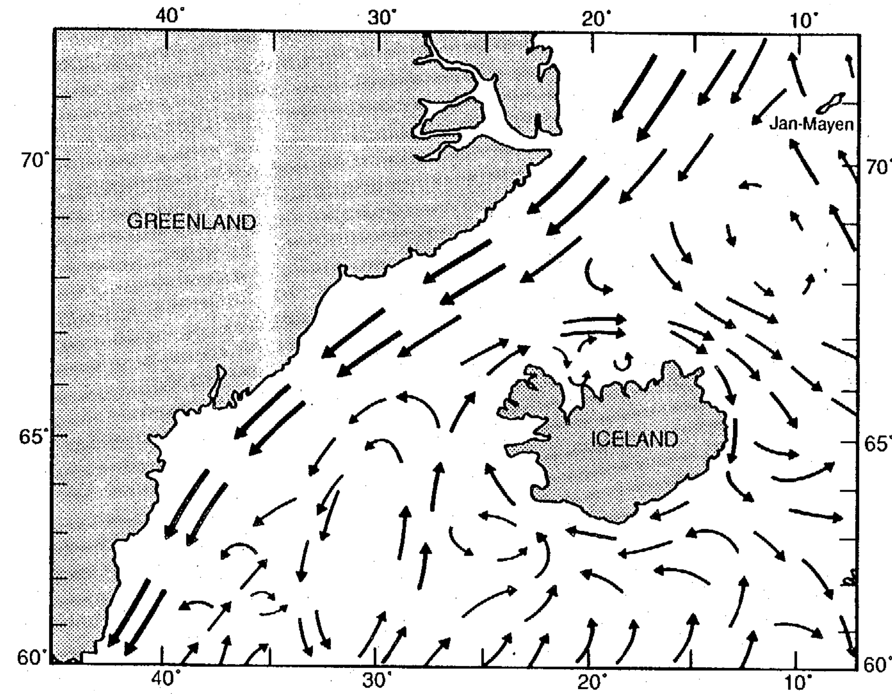

Figure 5. *Currents in the vicinity of Iceland (after references 44, 47-49).*

the entrance to Norton Sound reflects the large scale offshore circulation in which net water transport is North toward the Bering Straits and prevailing winds which tend to be out of the south at this time of the year.[52,54]

Within Norton Sound itself, the distribution of the phytoplankton pigment concentrations delineates some of the regional oceanography. Circulation is generally weak, cyclonic, and can be divided into two distinct regions between Cape Darby and Stuart island.[50,51] The direction of flow is evident in both images from the distribution of pigments in the water and by the plume of suspended sediments from the Yukon River. The river discharges large amounts of sediment and water during spring breakup (estimated at 88×10^6 tons annually).[56] Part of the plume appears to travel north across the entrance to Norton Sound while the remainder flows westward into the Bering and eastward along the shoreline of the Sound. Within the Sound, the plume travels along the coast to Stuart Island where a small portion turns north toward Cape Darby. The remainder continues along the southeastern shore of the Sound.

CONCLUSIONS

This study of CZCS imagery from two different high latitude locations demonstrates that, despite constraints imposed by cloud cover and algorithm limitations, the CZCS is a valuable means for studying mesoscale physical and biological oceanographic phenomena in the Arctic and Antarctic. Persistent cloud cover in both polar regions can limit the observation of specific phenomena but, where cloud-free areas are available, the imagery provides detailed information on the complex open ocean and ice edge processes as well as occasional time series which make it possible to follow these processes over varying periods of time. Presently, uncertainties in the algorithms prevent use of quantitative CZCS pigment retrievals but the relative distribution patterns of phytoplankton pigment reveal a great deal about the relationships between oceanographic processes and biological production. It is hoped that the research now being carried out on algorithm refinement for high latitude imagery will confirm the accuracy of pigment concentrations derived from this data.[58]

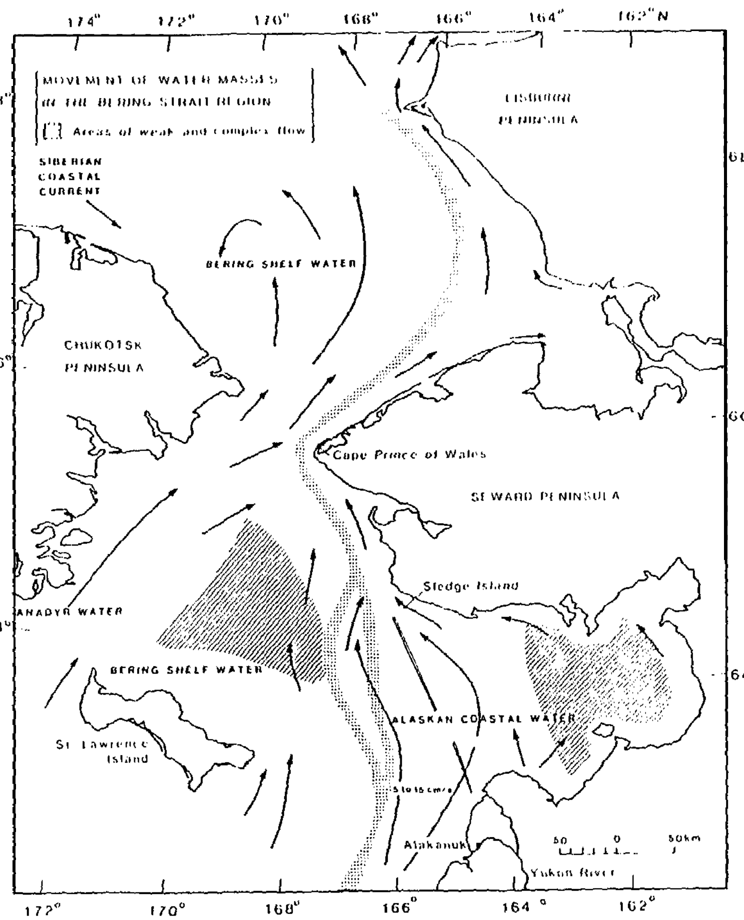

Figure 6. *Water mass movement in the Bering Strait Region (Source: Drury et al.[57]).*

This analysis focused on the marginal ice zone, a unique environment because of its important role as a habitat which supports extraordinary concentrations of biomass as well as a complex and dynamic interface between the atmosphere and the ocean. Imagery processed in the marginal ice zone from two different areas illustrates how successfully the CZCS can be used to study this environment. The first example, at the ice edge between Iceland and Greenland, shows the development of an ice edge bloom in early spring and the influence of the local currents on the shape and orientation of the bloom. The position of the bloom in and along the edge of the most actively melting ice reflects the importance of the ice edge to phytoplankton growth and development. The southern edge of the bloom forms an eddy which probably results from the influence of local winds as well as the Irminger and East Greenland Currents which converge in this area and form the northern portion of the cyclonic eddy in the Irminger Sea.

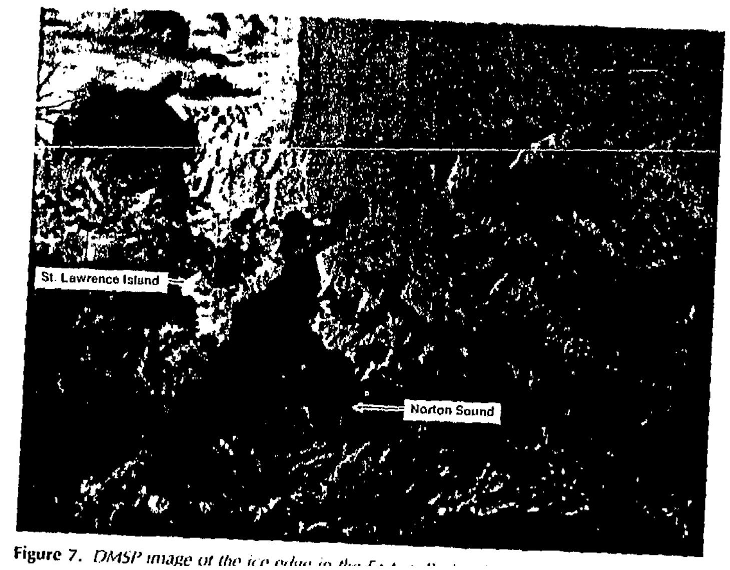

Figure 7. *DMSP image of the ice edge in the ...*

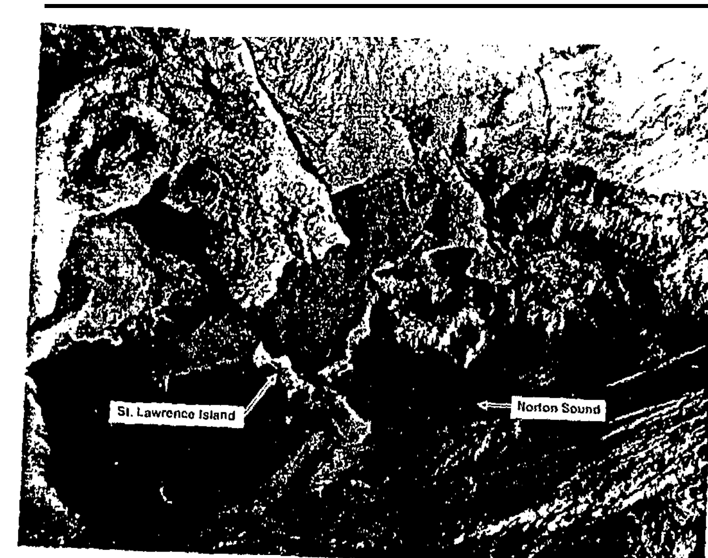

Figure 8. *DMSP image ... Bering Sea and Norton Sound*

The second example, two images [illegible] the Norton Sound area of the Eastern Bering Sea, also illustrates the influence of the ice on phytoplankton growth and highlights several important physical oceanographic features of the Norton Sound area. It is well known that in the Eastern Bering Sea, intense phytoplankton blooms are associated with actively retreating ice fronts. When DMSP imagery for the same two days is compared with the CZCS pigment distribution, the influence of the ice is clear, particularly in the region where ice is melting and slushy. Significant levels of chlorophyll can be seen trailing the retreating ice pack in the first image; whereas, in the second, low values are present along the now sharper, more solid ice edge where there appears to be considerably less active melting. The distribution of the pigments in the bloom outside the entrance to Norton Sound reflects the large-scale [illegible] water than sport is north flow and the Bering Straits and prevailing winds which tend to be out of the south at this time of the year. Within Norton Sound itself, the distribution of the pigments delineates some of the regional oceanography. The direction of the [illegible] weak, cyclonic flow is evident in both images from the distribution of pigments in the water and by the plume of suspended sediments from the Yukon River.

Thus, it appears that CZCS imagery can provide, at marginal ice zones and high latitude locations in general, a valuable assessment of the relative pigment concentrations as well as the physical processes driving biological production. Synoptic mesoscale information of this kind will, in turn, provide a better understanding of the contribution by high latitude production to the primary productivity of the global ocean.

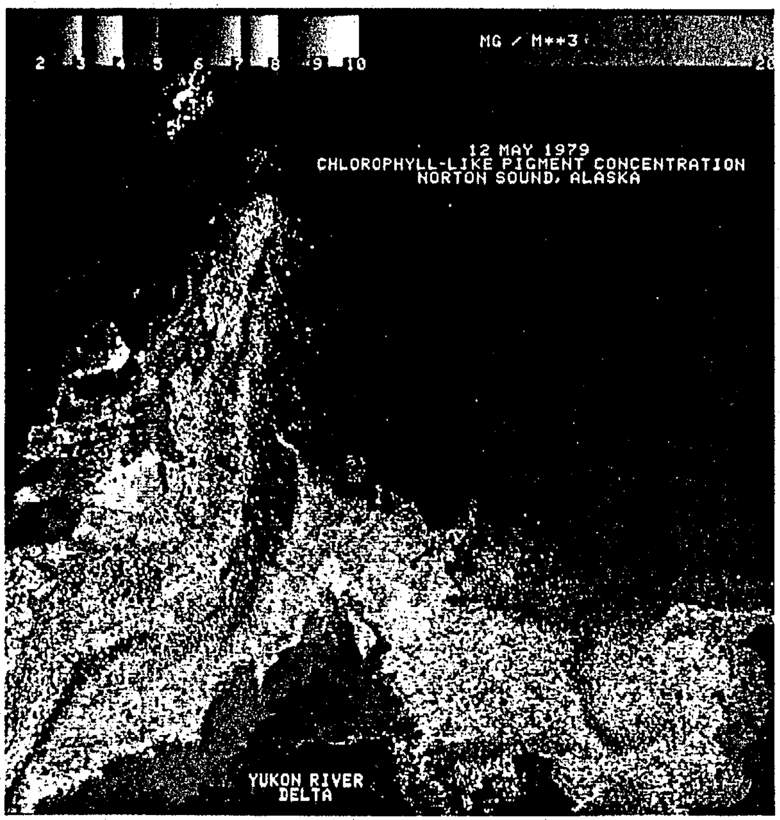

Figure 9. *CZCS false color image of the retreating ice edge in the Eastern Bering Sea and Norton Sound, 12 May 1979.*

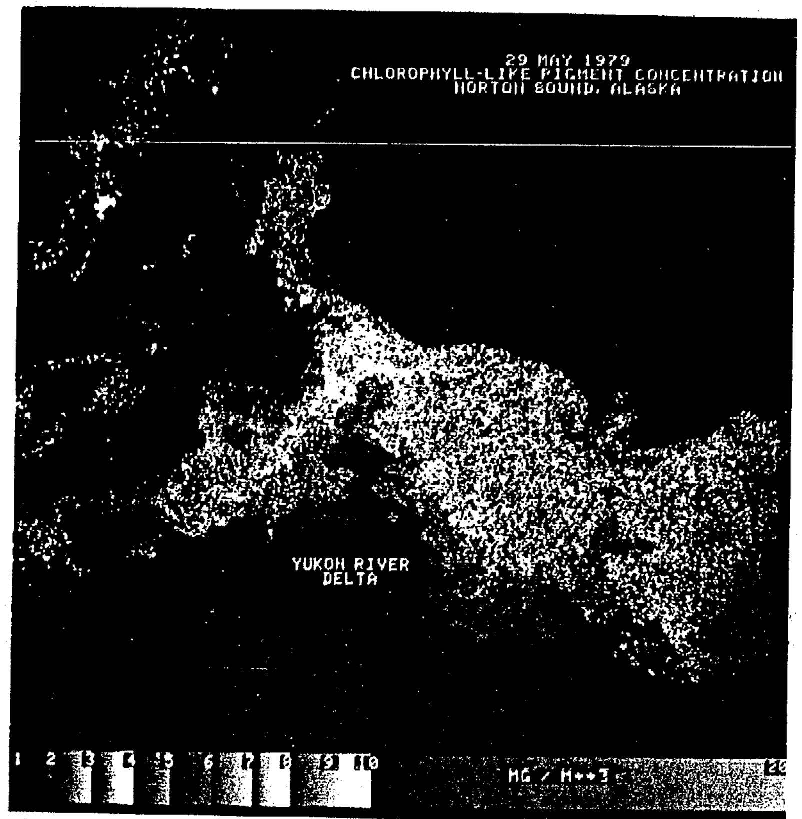

Figure 10. *CZCS false color image of the retreating ice edge in the Eastern Bering Sea and Norton Sound, 29 May 1979,*

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A FEASIBILITY STUDY ON

SATELLITE AND VHF TRACKING OF

MARINE MAMMALS

Report to

The Commission for Scientific Research in Greenland

and

Greenland Fisheries and Environment Research Institute

from

Danbiu ApS. (Biological Consultants)
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