numbers recorded by the shore observers six times. In three instances of poor (white caps and 4-6 foot swells) sea state conditions, on the other hand, the aerial observers were unable to confirm groups or individuals sighted by the shore observers. These data suggest that, although aerial observations may be more directly limited by sea conditions, they are useful in quantifying the number of whales in groups. Further, resolution of numbers present is faster from the air than from shore. (It often takes the shore observers up to 30 minutes to determine their count for a given group—during which time the individuals in the group may dissociate or join with others.)

Resolution of numbers of whales in groups is more rapid and apparently more accurate from the air than from shore. With a professional spotter pilot working a limited area—such as that scanned by the shore observers—in good sea state conditions, essentially no whales will pass unnoticed. "Misses" by the aerial observers were due to leaving the area prematurely in order to accomplish other tasks; had the aircraft been consistently in the shore observers' area (and immediately outside to prevent unnoticed passage of individuals offshore) none would have gone unrecorded.

The aerial observers made 50 observations of whales involving 149 animals. All these observations occurred within 7 miles of the shoreline, even though the area surveyed extended to 25 miles seaward. Of these sightings, 98 percent were within 5 miles of shore, 96 percent within 3 miles, and 94 percent within 1 mile. Distances were estimated by making timed runs at constant speed from positions offshore to the coastline. The observations of this study tend to confirm Rice and Wolman's statement that 95 percent of the whales pass within 1.9 km (1.2 miles) of the shore near the Yankee Point site.

Gray whales have been reported interacting with other marine mammals by Leatherwood (1974b), but during this study no other marine mammals were observed "associating" directly with gray whales. Feeding behavior was observed on two occasions. A calf was seen accompanied by an adult. These two latter observations are of particular note and the senior author intends to publish the details elsewhere.[1]

[1] Sund, P. N. Manuscript. Evidence of feeding during migration and of an early birth of the California gray whale.

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MFR PAPER 1058

Telemetering of Temperature and Depth Data From a Free Ranging Yearling California Gray Whale, *Eschrichtius robustus*

W. E. EVANS

ABSTRACT

In 1968 the author initiated a series of studies using radio transmitters to follow the movements and study the diving behavior of small toothed whales. This paper describes the modifications of this equipment necessary to use this technique on larger whales, in this case a yearling California gray whale, Eschrichtius robustus. *In addition to the transmission of positional data, i.e. azimuth and depth of dive, the instrumentation package used in this study was designed to transmit environmental data (temperature-at-depth). The animal used in this study, a female* E. robustus, *was captured on 13 March 1971, in Scammon's Lagoon, Baja California Sur, Mexico, by Sea World, Inc., San Diego, and released on 13 March 1972, at lat. 32°41.5′N, long. 117°20.5′W (off Point Loma, San Diego, Calif.) by the Naval Undersea Center (NUC), San Diego. Radio contact was maintained with the animal until 5 May 1972. Depth of dive and temperature-at-depth data were continuously monitored for a 24-hour period.*

INTRODUCTION

The present study is an extension of a 6-year research program designed to evaluate the feasibility of using medium-sized to large cetaceans, instrumented with a combination data collection and transmission system, to measure physical oceanographic parameters at various depths, and to evaluate the relationship of these parameters to cetaceans' movement patterns and secondary productivity (Evans, 1970, 1971, in press).

Because of the impending release of a yearling California gray whale

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(Gigi II) captured by Sea World, Inc., San Diego, on 13 March 1971, in Scammon's Lagoon, Baja California, Mexico, and the timing of the northern migration of California gray whales (March-April), the program was accelerated to take advantage of this opportunity. The prototype data transmission/acquisition system had been designed and bench-tested in anticipation of tests on a Pacific pilot whale, *Globicephala* cf. *scammoni*, in midsummer 1972. The unit was repackaged and the test dates subsequently moved up to coincide with the planned release of the Sea World captive yearling gray whale which was scheduled for 13 March 1972. It was then field tested attached to the Sea World gray whale when she was relased at 0905 hours at lat. 32°41.5′N, long. 117° 20.5′W into a group of four to five California gray whales moving north.

DATA PARAMETERS

Since one of our primary purposes for using a data system attached to a cetacean was to measure environmental parameters associated with the animal's movements below the air-sea interface, the instrumentation used must indicate the depth at which the measurement was made. The following parameters were considered as potential indicators of productivity and important correlates of cetacean movement:

1. Temperature at depth.
2. Ocean current speed at surface and at depth.
3. Salinity-derived from conductivity measurements.
4. Dissolved gases:
   a. O_2;
   b. N_2;
   c. Free CO_2.
5. Light:
   a. Absorption loss due to molecular absorption, particulate matter;
   b. Backscattering from particulate matter;
   c. Light level at depth.

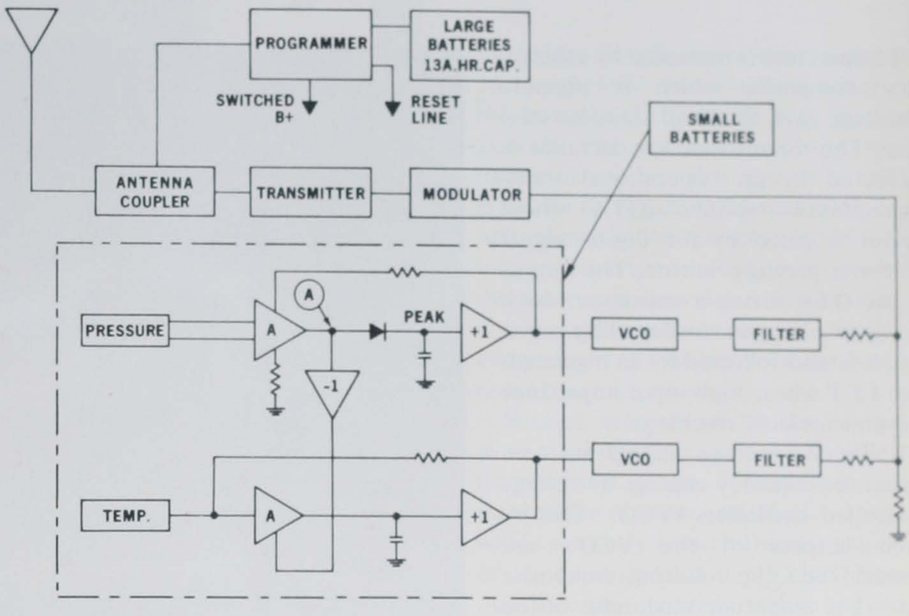

Figure 1.—Block diagram of telemetry transmitter attached to yearling California gray whale (Gigi).

After consideration of all these parameters, temperature was selected as the most desirable for this phase of the program because: 1) methods of measurement are straightforward electronically, 2) considerable bathythermal data exist for the California Current region, 3) data transmitted from the instrumented animal could be easily checked by use of currently available expendable bathythermographs, and 4) a great deal of data relating the thermal structure of the water columns to primary and secondary productivity are available in the scientific literature (e.g. Eckman, 1953).

INSTRUMENTATION

Data Transmission System

The data acquisition system mounted on the yearling gray whale provided measurement of the depth of each dive and the water temperature at that depth, and served as a radio beacon for tracking. Data measured was telemetered by an 11 meter transmitter (27.585 megaHertz) to either a surface vessel, shore station, or aircraft-based receiving set which would also demodulate the data being transmitted. Directional information for tracking was obtained by a special fast response automatic direction finder developed several years ago specifically for this type of application (Ocean Applied Research Corporation, San Diego, Model ADF210).[1]

A block diagram of the telemetry transmitter is shown in Figure 1. Function and operation are as follows:

Pressure is measured by a semiconductor strain-gauge bridge excited with constant current. The output voltage is amplified by three operational amplifiers connected in an "instrumentation amplifier" configuration and the peak pressure reading stored (remembered) on a capacitor which is followed by an insulated-gate field-effect transistor (FET). This peak detector is inside the feedback loop of the amplifier which maintains accuracy and also yields a digital zero at point A when pressure is decreasing from the peak depth. This level is used to hold the temperature reading.

[1] Use of trade names in this publication does not imply endorsement of commercial products by the National Marine Fisheries Service.

Temperature is measured by a thermistor composite which is pressure protected in a thin-wall stainless steel tube. The thermistors' conductance is measured by an "operational transconductance amplifier" (OTA) whose output is gated by the digital signal from the pressure sensor. The output of the OTA drives a capacitor which serves as a temperature-reading memory. It is also followed by an insulated-gate FET whose high input impedance prevents memory discharge.

These two voltage analogs are converted to frequency analogs by voltage controlled oscillators (VCO). The filtered outputs of the VCO's are summed and the resulting composite fed to the amplitude modulator of the 3-watt peak transmitter.

A programmer is also included to provide a 4-second data transmission time when the animal first surfaces followed by a series of short pulses which are adequate for the tracking system. A seawater connection between the antenna tip and the instrument case generates a delayed reset for all capacitor memories and the programmer.

In the package used on the yearling gray whale two batteries were included

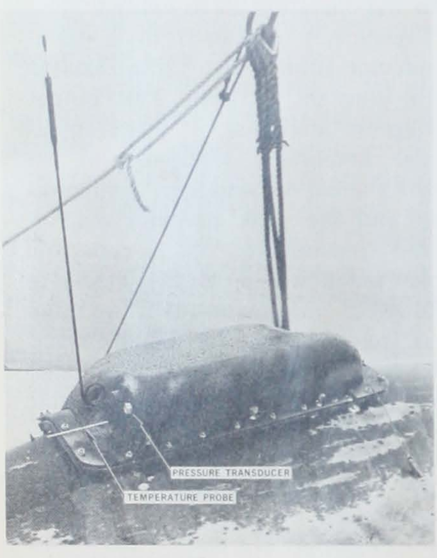

Figure 2.—Photograph of the Ocean Applied Research Corporation data transmitter Model WDT-920 attached to the Sea World yearling gray whale (Gigi) just prior to release. (Photo courtesy of J. S. Leatherwood.)

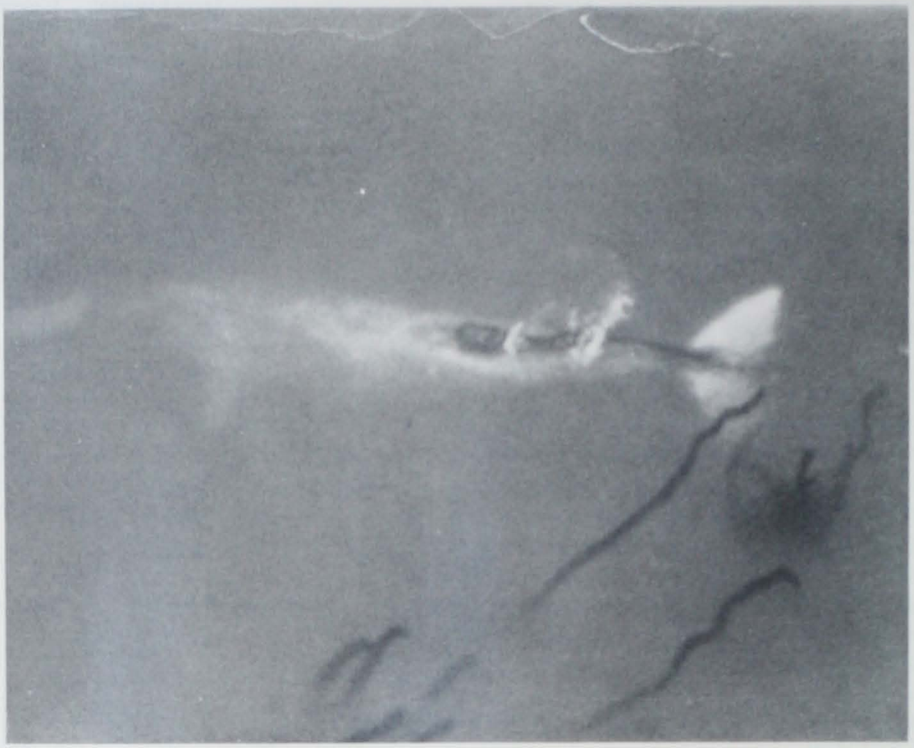

Figure 3.—Aerial photograph of test animal taken on 16 March 1972, as she was swimming through kelp beds off San Clemente, California. (Note kelp trailing behind the transmitter package.) (Photo courtesy of J. S. Leatherwood.)

in the system. One had a capacity of 13 ampere hours and was used to power all electronics which were on when the animal was at the surface. The second, smaller, battery, which had a 1.2 ampere hours capacity, powered the depth and temperature instrumentation continuously. The expected life of the smaller battery was approximately 1 month while the larger battery with its greater capacity and reduced duty cycle should continue to provide tracking transmissions for as much as 9 months. The entire system packaged and attached to the whale is shown in Figure 2.

During the first month of operation,

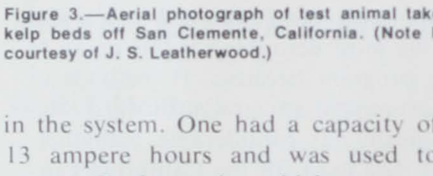

Figure 4.—Block diagram of the telemetry data receiving and recording system.

performance of the Instrument/Beacon package was satisfactory with the notable exception of transmission range which was initially more than 25 miles. Subsequent tests indicate that the antenna, which is a top loaded stainless steel whip antenna, had sustained some damage. The animal was, on two occasions, observed swimming through kelp and kelp was seen hanging on the antenna, Figure 3. California gray whales are also known to rub on the bottom, a behavior which could have abraded or even severed the loading coil from the antenna, drastically reducing its radiation efficiency. The estimated useful range of the damaged system was on the order of 10 miles.

The original antenna design employed on beacon transmitters for marine mammals (specifically porpoises) was an adaptation from a design which had been in use for some time on radio beacons used for the recovery of oceanographic instruments. It con-

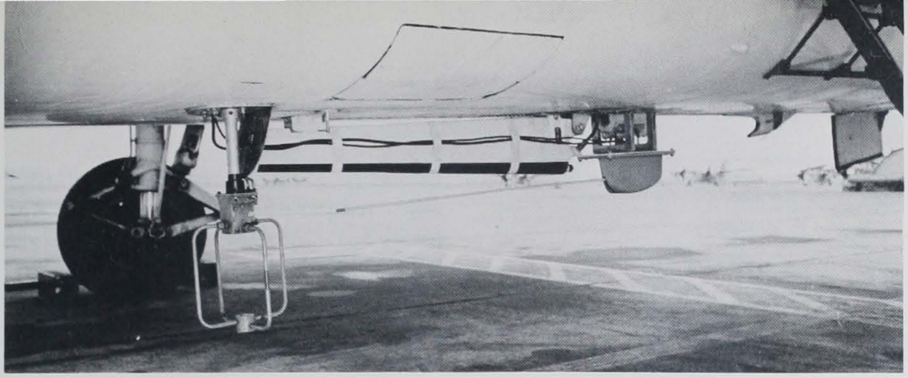

Figure 5.—Automatic direction finding antenna (loops) and data acquisition antenna (whip) attached to the belly of a U.S. Navy S-2 tracker aircraft. (Photo courtesy of J. S. Leatherwood.)

sisted of a solid fiberglass tapered rod onto which was wound a conductor and loading coil. An aluminum tip served both as a seawater contact and as a section whose length could be trimmed for peak field strength. A proprietary coating protected the conductor and coil from seawater. The antenna was entirely successful on *Delphinus* species (Evans, 1971), but problems were encountered when a similar design was used on captive whales such as pilot whales and killer whales. The captive whales invariably broke the antennas by rubbing on structures or boats and in the instance of the release of a pilot whale into the wild, the antenna was broken by seaweed. Subsequently, a spring-wire antenna was designed which could be severely bent without catastrophic damage and has been used successfully on the aforementioned whales (Martin, Evans, and Bowers, 1971). This type of antenna was used on the gray whale pack. Subsequent simulations of various types of damage to this antenna indicate that modifications would be in order before employing this type of antenna again. Specifically, the arrangement of the spring at the base should be changed to allow the antenna to be bent double against the transmitter case without damage. The antenna should be lengthened somewhat to reduce the variation in impedance for a given variation in the relative position of the ground plane (sea surface) and the loading coil should be fully encapsulated in the nonmetallic antenna's structure to completely eliminate the abrasion damage potential.

Data Receiving System

The data receiving and recording system illustrated in Figure 4 was originally tested on board the NUC RV *Cape*. Subsequent to the initial tracking and data acquisition attempts following the release of the whale on 13 March 1972, the system was placed on board a U.S. Navy S-2 tracker aircraft. The antenna mounting configuration used on this type of aircraft is shown in Figure 5. The whip antenna is shown in the retracted mode. The loop antenna used in conjunction with the automatic direction finding system is adjustable and was aligned prior to every flight by using a shore-based radio beacon.

Several relocations of the animal were made using this system. The short transmission range of the damaged transmitter system attached to the whale seriously limited the acquisition of temperature and depth data from the aircraft-mounted system. Tests

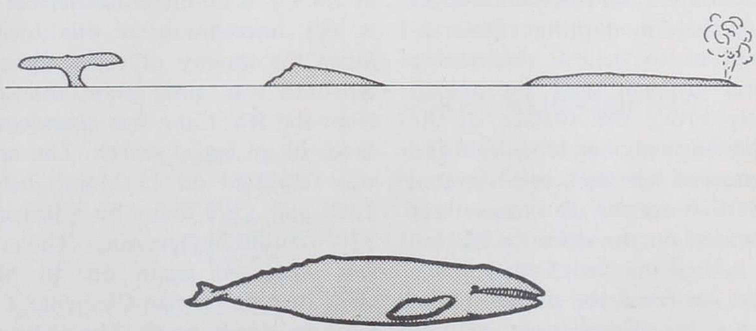

Figure 6.—California gray whale breaking the surface exposing only the head and fore-part of the back. The normal sequence of a blow is shown right to left at the bottom of the figure, note exposure of the dorsal ridge. (Photo courtesy of J. S. Leatherwood.)

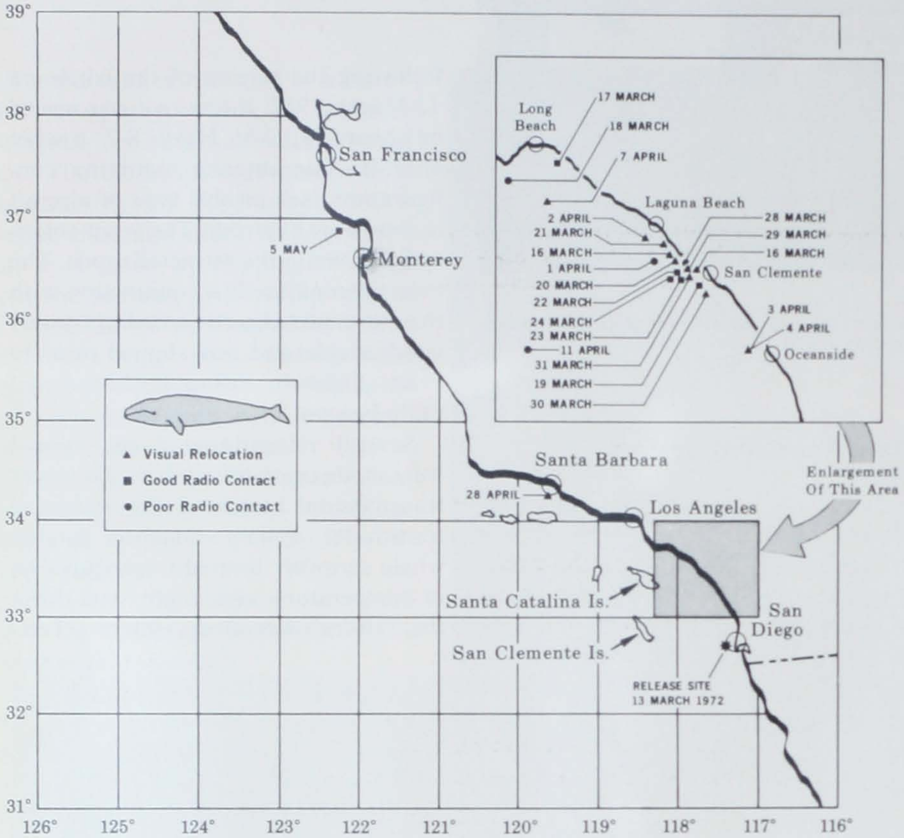

Figure 7.—Map of California coastline showing locations of the Sea World yearling gray whale (Gigi) 13 March-5 May 1972.

conducted following the release of the whale using a similar data transmitter with one-third the power of the system used on the test animal and a modified antenna have yielded data acquisition ranges up to 40 nautical miles.

RESULTS

During the initial 2 hours after release of the test animal, signals were very intermittent and seldom longer than 2 seconds in duration. Observations lead us to believe this was a behavioral problem since the animal frequently broke the surface of the water showing only her blow hole and mid-portion of her back as illustrated in Figure 6. Since the data transmitter was mounted on the dorsal ridge (on the last half of the body) the antenna either did not break the surface of the water, thus no transmission, or only the tip of the antenna broke the surface, resulting in a very short duration transmission.

This resulted in limited data reception during the first 2 hours after release and subsequent loss of the animal's location and movement pattern. Those signals over 2 seconds in duration that were received during this time period did indicate temperature-at-depth values reasonable for the location and time of year (e.g., above 20 meters temperatures of 13°-14°C and below 20 meters a temperature of 7.4°C). A 20-meter isothermal layer is not uncommon at this location. Since the quality of radio signal acquisition was quite poor, the search from the RV *Cape* was abandoned in favor of an aerial search. The animal was relocated on 15 March between 1300 and 1500 hours on a bearing of 320°T south of Oceanside. The animal was relocated again on 16 March close inshore off San Clemente, Calif., working slowly north. The photograph shown in Figure 6 was taken at this time. On this flight and those that followed, although the animal could be easily located, acquisition of useable temperature-at-depth data was limited 1) by the long time interval between adequate exposure of the antenna, and 2) by the apparent short range of the transmissions received. Areas of visual relocation and radio contact from 16 March 1972 to 5 May 1972, are illustrated in Figure 7.

After a period of 5 to 6 days, the animal's swimming pattern changed and longer and more frequent transmissions were being received. In order to verify these observations and, if possible, to collect temperature-at-depth data over a 24-hour period, the RV *Cape* left San Diego at approximately 1600 hours on 20 March 1972 for the Dana Point-San Clemente, Calif. area. At 1840 hours, 35 nautical miles from San Clemente, Calif., we acquired weak signals from the animal bearing 340°T. At 2300 hours, signal level had increased and we were receiving bearing and temperature-at-depth data. Initial data indicated temperatures of 12°-14°C at depths of 15-20 meters. At 2350 hours the animal's diving behavior changed and indicated some dives to depths of 170 meters. Triangulation placed the animal at a location approximately on the 100 fathom curve, 1.7 nautical miles off Laguna Beach, Calif. (Aliso Canyon). Although the depths recorded at this location were realistic if the animal was diving to the bottom, the water temperatures at those depths appeared to be anomalous. At this

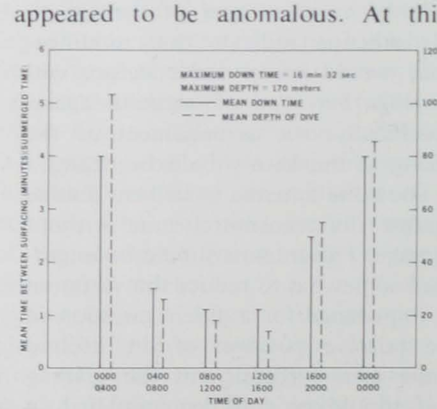

Figure 8.—Mean down times and depths of dive as a function of time of day recorded 20-21 March 1972.

time of the year one would expect surface temperatures between 12° and 14°C, and temperatures at 170 meters of 7°-8°C or less. Data from the animal, however, indicated temperatures-at-depths of 100-170 meters ranging from 10° to 14°C. If these levels were indeed accurate, a significant temperature inversion layer was present. This cruise was terminated at 2100 hours on 21 March 1972, after having recorded data for approximately 24 hours. In addition to the temperature-at-depth data, the following observations were made:

1. The animal was offshore 1-2 nautical miles after sunset, moved inshore 100-200 meters from the beach post-sunrise.

2. The diving pattern at night was regular, as compared to an erratic pattern during daylight hours.

3. The animal was observed in Dana Cove along with three other gray whales of a similar size range. All four animals left the Cove in late afternoon.

4. The mean time between transmissions was significantly longer from 1600 to 0400 hours than during the remainder of the day (Figure 8).

Since transmissions were more predictable after sunset, our aircraft data acquisition flights were scheduled at night. Under this plan, data were collected on 28 and 29 March from the S-2 tracker aircraft in the vicinity of Dana Point, Calif. The recorded data from these flights indicated dives of 50-80 meters and temperatures of 12°-14°C. The observations that the animal moved offshore (1-4 miles) at night were verified.

No readily apparent explanation was available for the relatively high temperatures recorded at depth on 20-21 March. To check on these measurements, the RV *Sea See* was sent to the Dana Point area to work from 6 April 1972 through 10 April 1972, equipped with an expendable bathythermograph (XBT) system capable of measuring temperature versus depth over a range of 0°C-30°C to depths of 450 meters. During the

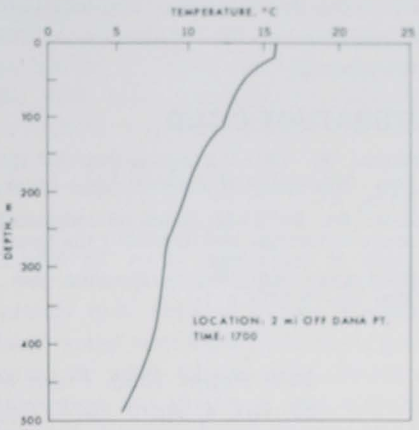

Figure 9.—A composite of three expendable bathythermograph plots collected 2 miles off Dana Point, California, at 1700 hours on 10 April 1972.

period 6-7 April, the area south of Dana Point was searched and no contact was made with the animal, although one small 7-8 meter whale was sighted. The XBT data, however, indicated surface temperatures of approximately 13°C which dropped to 6°C at 300 meters, with no obvious thermocline or temperature inversion. Late on 7 April, a search was made north of the Dana Point area by automobile and signal acquisition was made from the Huntington Beach pier at 1600 hours. Observers on the pier claimed to have sighted a small California gray whale with a radio pack swimming north 100 meters off the end of the pier at 1000 hours on that same day. Our signal acquisition was on a bearing of 280°T which would

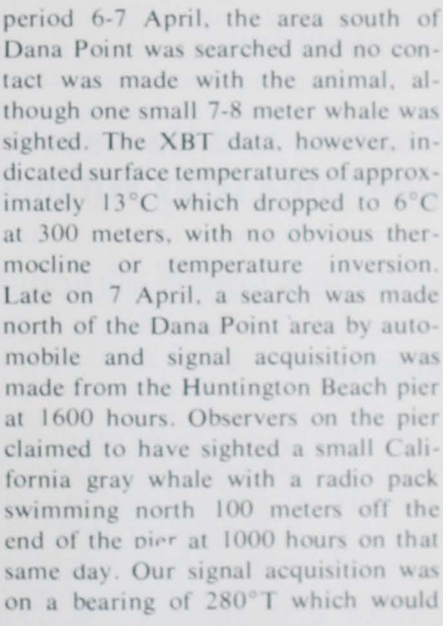

Figure 10.—A composite of three expendable bathythermograph plots collected 1.7 miles off Laguna Beach, California, at 1800 hours on 10 April 1972, compared to temperature versus depth data collected from Gigi on 20 March 1972.

place the animal between Seal Beach and Santa Catalina Island.

On 10 April 1972, the RV *Sea See* started a search north of Dana Point at 1600 hours. The first XBT station was at 1700 hours, 2 miles off Dana Point. A plot of temperature versus depth representative of the three measurements taken at this location is presented in Figure 9. The vessel moved north to approximately the same location where the temperature-at-depth data were collected from the whale on 20 March. Of major interest here is indication from the XBT data that a rather significant temperature inversion did exist in this area. A plot of the XBT station taken at 1800 hours on 10 April, 2 miles off Laguna Beach compared to the temperature-at-depth data transmitted from the whale is illustrated in Figure 10. It should be noted that although the relationship between the XBT and whale data appears to be comparable at depths of 100-200 meters, these are preliminary data. Conclusion should not be made without further verification of the thermal inversion shown in Figure 10. It is possible that the outfall of the San Onofre nuclear power plant north of this location is dumping warm water back into the sea. It has also been shown that at this time of year the mean geostrophic flow at 200 meters has northbound components (Wyllie, 1966). Depending on the temperature, volume, and depth of the San Onofre effluent it is not inconceivable that inversions such as that shown in Figure 9 could result. This, however, is pure speculation at this point.

ACKNOWLEDGMENTS

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ment the whale and subsequently track and obtain data from it was designed and manufactured by Ocean Applied Research Corporation, San Diego, California. Hugh Martin and Romaine Maiefski, both from this organization, actively participated in the attachment of the instrumentation to the animal and the initial stages of tracking. J. S. Leatherwood, J. Hall, Bruce Parks, and L. McKinley, of the Naval Undersea Center, San Diego, California, and the Commanding Officer of the RV *Cape* and his crew were directly instrumental in the success of this project. The radio contact with the instrumented whale on 5 May 1972 was accomplished by Paul Sebesta, NASA Ames Research Center, Moffett Field, Calif., using equipment supplied by the author.

POSTSCRIPT

During the period 2 January 1973-21 March 1973, the author investigated 37 reported resightings of Gigi. Although most of these reports did not check out, on 5-6 January, a Captain Paul Roth, USN, and a Mr. and Mrs. Sherwood of San Diego independently described behavior of a 9-10 meter California gray whale sighted inside the kelp off the Sunset Cliffs area of Point Loma, San Diego, California. In both cases the whale, light in color, approached close to small vessels less than 10 meters, rolled, and frolicked around. On 15 March we received a report from the MV *Long Beach Prince* that a whale of similar size and with white tail flukes (see Figure 3) and a 60 cm × 60 cm square white scar behind the blow hole was sighted frolicking around the vessel by 178 whale watchers. The location of this sighting was 3-4 miles off Point Fermin. This latter sighting is especially interesting since on 6 March 1972, one week prior to release, Gigi II was branded using cryogenics with a 60 cm × 60 cm mark, midline on the back just posterior to the blow hole. This form of marking, called "freeze branding," results in a white scarring due to the destruction or displacement of melanin in the epidermis of the area treated.

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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 for 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 ashore, 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 actorostrata*). 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 (Clarke, 1957) our knowledge of whale migration remains highly incomplete. Because such information is needed for some protected species, new tag-