

Satellite Sea Turtle Tracking

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Introduction

For years, marine biologists have aspired to develop a means of recording the daily movements and migration routes of far-ranging animals such as the various species of sea turtles. Such knowledge would define preferred turtle habitats, locate nesting sites, provide foraging and behavioral data, and direct administrators toward sound management decisions.

Historically, marine turtles have been tracked with flipper tags (Caldwell, 1962), tethered floats (Carr et al., 1974), balloons (Carr, 1962), and radio beacons (Carr et al., 1972). Flipper tag returns rely on the chance returns by others and make a study very unreliable. Tethered floats and balloons are extremely expensive for they require a continuous support vessel to maintain visual contact, and they are restricted to fair-weather operation. Tracking with radio beacons, also costly, has been done with some success, but the experiments were limited to short duration and restricted range.

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Our research study provides an alternative: Tracking sea turtles with a satellite receiving system.

Methods

Background

The feasibility of tracking wild animals by satellite was originally demonstrated by Craighead et al. (1972), when an elk was tracked for 28 days with the NIMBUS 3 weather satellite. In 1977, the U.S. Fish and Wildlife Service (FWS) successfully tracked polar bears (Kolz et al., 1980) using the NIMBUS 6/Random Access Measurement System (RAMS) (Cote et al., 1973).

The transmitter used for tracking the polar bears was constructed by the Handar Company¹, Santa Clara, Calif. It consisted of a transmitter module (14 × 14 × 5 cm) and a 5 kg plastic attachment collar which contained the battery pack. The module contained the temperature-controlled oscillator, radio transmitter circuits, timing controls, and antenna. The coplanar antenna was contained in

¹Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

the lid of the transmitter module. Lithium batteries encapsulated in the collar served as the power supply with sufficient capacity for 1 year's operation. The instrument was designed to transmit pulses to the satellite for an 8-hour period every fourth day. This low-duty cycle was necessary to conserve the batteries, extend the transmitter operating life to 1 year, and reduce the total package weight.

This transmitter-collar unit was attached to a polar bear near Point Barrow, Alaska, and tracked by the satellite system for 390 days and over 1,000 miles. Although there are drastic physical and behavioral differences between polar bears and turtles, the NIMBUS satellite system and the hardware developed for the bear transmitter offered an approach which could be adapted for marine turtle tracking.

Satellite Tracking Equipment: The NIMBUS System

The NIMBUS 6/RAMS satellite system is a data collection and transmitter location system designed to collect meteorological and oceanographic data transmitted from randomly located mobile transmitters. The system is capable of handling the random transmissions for 200 transmitters within its field of view with a maximum of eight signals occurring simultaneously. The satellite storage capacity allows for 1,000 transmitters worldwide.

Data are transmitted to the satellite as 401.2 MHz radio frequency (rf) pulses. These pulses have a duration of about 1 second and occur at a rate of approximately one pulse per minute. Each pulse

*ABSTRACT—A female loggerhead sea turtle, *Caretta caretta*, weighing 96 kg was instrumented with a buoyant cylindrical radio transmitter developed jointly by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service. The transmitter was attached to the rear edge of the turtle's carapace*

with a nylon tether, and the turtle was tracked by the NIMBUS 6 satellite system for 8 months during 1979 and 1980. The turtle was released about 20 miles off Mississippi into the Gulf of Mexico and traveled west and south to within a few miles of Brownsville, Tex. The total tracking distance exceeded 1,400 miles.

contains a period of unmodulated carrier and a phase-modulated section for data synchronization, transmitter identification, and sensor data (if included). The unmodulated portion of rf carrier is used to measure the doppler frequency shift and calculate the latitude and longitude of the transmitter. The system is capable of determining a position to within ± 5 km. This accuracy is a function of the number of messages received by the satellite in a given orbit. A minimum of four messages per orbit must be received in order for a position to be computed.

Preliminary Technical Considerations

The National Marine Fisheries Service (NMFS) and the FWS agreed to modify the hardware developed for polar bear satellite tracking into an instrument package suitable for attaching to a large sea turtle. Technical questions concerned the quality of signal that could be transmitted from a coplanar antenna floating directly on the ocean's surface because of possible signal distortions caused by surface reflections. Therefore, one test objective was to prove the feasibility for satellite tracking under these conditions.

Although the transmitter module for the polar bear was not of optimum size or shape, it was both expedient and economical to repack for marine use. We therefore considered various enclosures for housing this basic module with an appropriate battery pack. The problem of attaching any package to a turtle was of real concern. Little is known about marine turtles, so the following guidelines were used.

- 1) The enclosure had to be watertight and capable of withstanding external water pressure. We arbitrarily selected a design specification of 200 pounds per square inch (psi) since no scientific data existed on expected pressure.

- 2) Radio signals could not be sent to the satellite from underwater. Therefore, the transmitter design had to maximize antenna exposure.

- 3) The package had to be smooth with no sharp edges or protrusions which could snag or catch on marine growths or other obstructions.

- 4) The package had to be constructed of low-loss dielectric material to allow radio signals to penetrate.

- 5) The package should have a small cross-sectional area to minimize drag and have minimal effect on a turtle's normal activity.

After considering these restraints, we concluded that a small cylinder towed by a lanyard offered the best solution in terms of available materials, strength, and simplicity. Prior research discouraged attachment of a rigid package directly to the turtle's carapace since turtles frequently surface with only their heads exposed. Therefore, the towed cylinder offered increased antenna exposure time and greater probability of reception. A cylinder 25 cm long and 15 cm in diameter was calculated to satisfy our requirements for weight versus flotation volume.

Captive Behavioral Studies

We intended to develop a package that would not substantially interfere with a turtle's normal behavior, and we devised tests to evaluate the degree of interference (obviously there would be some). Therefore, a cylindrical model of a transmitter was constructed, using plastic pipe fittings. The complete cylinder weighed 3.1 kg in air and floated 40 percent exposed or approximately 1.8 kg positively buoyant. This model was fastened by a nylon tether to the rear edge of the carapace of a 91 kg loggerhead turtle, which was the minimum size turtle considered for this tracking experiment. The turtle was released into a large aquarium at Marine Life Park, Gulfport, Miss., and observed for any abnormal behavior. Aside from some initial problems with the attachment method, no significant problems were observed. However, we decided to use a more precise evaluation method.

A cylindrical recording device (6.4 cm in diameter and 7.6 cm long) was then developed by the FWS electronics staff to quantify the surface behavior of a sea turtle. This recorder sensed the electrical resistance between two external electrodes that were either exposed to air as the cylinder floated on the surface or surrounded by conductive seawater when the turtle surfaced. Electronic components tallied each time the electrodes were exposed to air, as well as data on the cumulative time the cylinder floated on the surface. We hypothesized

that surface time would be one of the most effective measures to monitor the turtle's behavioral responses to the added buoyancy of the satellite transmitter package. We assumed that the small size of the recording device would have negligible effects on a large turtle.

Two 3-day tests were conducted at the Marine Life Park with the recording device: First, with only the small recording cylinder attached to the 91 kg sea turtle, and then with both the transmitter model and recording cylinder attached. The results indicate the turtle decreased the "number of surfacing" times from 5,357 to 3,489 and increased its total surface time from 16.5 percent to 29.7 percent when the transmitter model was attached. These absolute surfacing counts are suspect because of errors caused by wave action, but the percentage of surface time is considered quite accurate. We concluded that the transmitter package caused the turtle to spend about twice as much time at the surface.

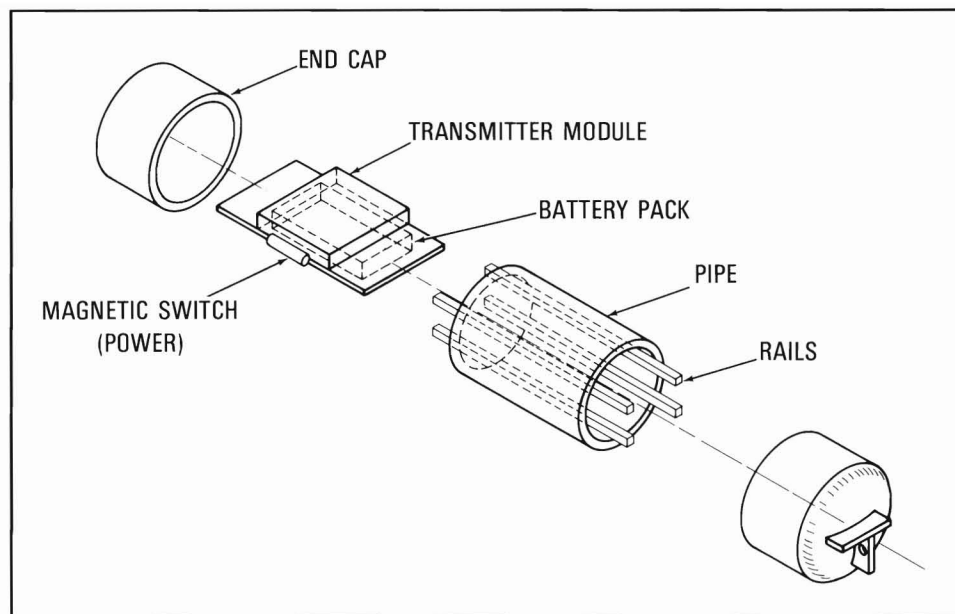
We recognize that sea turtles in the wild may react differently, but this test seems to indicate that the turtle adapted to the added buoyancy without radical behavioral change. Within our limited time, we could conceive of no other simple test to provide a better indication of the turtle's adaptation to the transmitter.

Prototype Transmitter

Structural Tests

Once assured that a large turtle could reasonably tolerate our transmitter package, we began to develop a strong structural design. Heavier PVC plastic pipe components than those used for the behavioral test model were obtained for destructive testing. This new model consisted of two pipe caps and a 10 cm length of 15 cm diameter plastic pipe. The end caps were PVC cemented to the pipe and then "welded" together, using a process in which a PVC filler rod is actually melted into the base material with a heat gun similar to metal welding. A T-shaped bracket made of 0.6 cm PVC flat stock was also welded to one of the end caps as an attachment point for the towing lanyard.

Figure 1.— Transmitter construction details.



This assembly was subjected to a hydrostatic pressure test and mechanical tension test. For the pressure test, the assembly was placed in a hydrostatic test vessel and subjected to increasing pressure until the end caps deformed at a pressure of 200 psi (equivalent to about 122 m depth). While this did not cause any internal leaks, we decided to regard this as the operational depth limit.

The mechanical tension test determined the strength of the attachment bracket. The transmitter model was secured in a test fixture and a shackle was attached to the bracket through an 0.6 cm hole. Increasing tension was applied to the bracket with a hydraulic test apparatus until the shackle was torn from the bracket. This occurred at a tension of approximately 264 kg which was far in excess of our requirements.

Construction Details

The construction details of the actual transmitter prototype are shown in Figure 1. All of the electronic components are attached to the 0.5 cm flat PVC plate. This plate was guided into the

pipe by the mounting rails and was held in position with epoxy. Weight and balance were carefully checked to assure that the coplanar antenna surface floated level in the water. The center of gravity for the package was adjusted by positioning the five organic lithium batteries (Mallory Battery Company Type LO 26), which were mounted under the transmitter module. This was sufficient to power the unit at the original timing cycle for a 1-year period. The completed package was sealed in exactly the same manner as the test unit.

Two magnetically operated reed switches provided the on/off control and timer circuit initialization without the need for access inside the transmitter package. One switch applied power to all the electronic circuits while the second switch initialized the basic 4-day timer. The transmitter module also contained a secondary radio beacon which continuously radiated 165 MHz rf pulses at a peak power level of -10 dBm. This full-time tracking transmitter operated independently of the satellite transmitter and allowed the turtle to be located at any time by search aircraft.

Final Preparations

Functional Transmitter Tests

The completed transmitter was thoroughly tested for compatibility with the NIMBUS system by using two independent signal reception modes: The spacecraft system and the Local User Terminal (LUT) (Schmid and Lynn, 1978) at NASA's Goddard Spaceflight Center. Actual conditions were simulated for these tests by floating the activated transmitter in a pool of seawater. Both receiving systems provided positive tracking data, and these results completed our testing program for the transmitter package.

The Captive Turtle

A 96 kg female loggerhead turtle was obtained from a Mississippi shrimp boat captain before the final hardware tests. This turtle, nicknamed "Dianne," was captured off Mississippi's barrier islands and placed in a reef tank aquarium at Marine Life Park. The completed transmitter was now attached to Dianne and

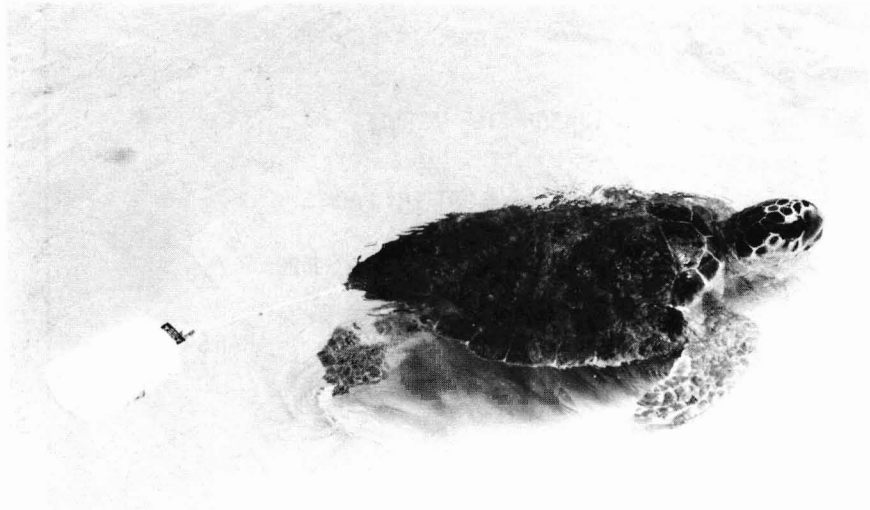


Figure 2.—Dianne swims with attached transmitter

she was released into an outdoor pond for observation (Fig. 2), where she seemed oblivious to the attached transmitter.

The Release

Intense shrimping activity prevented Dianne's return to her capture site. Therefore, Dianne was released farther offshore into the Gulf of Mexico (lat. 30°5'N, long. 88°46'W) at 1230 hours on 16 October 1979. This position is about 20 miles south-southeast of Biloxi, Miss. As soon as the turtle was overboard, both visual and radio contact were lost for the rest of the day.

Tracking

During the entire experiment, there were three sources of position for the animal: Aircraft, spacecraft, and LUT (Schmid and Lynn, 1978). The aircraft tracking was accomplished using a chartered, fixed-wing aircraft equipped with directional wing-mounted antennas. Position fixes were obtained using standard radio direction finding (RDF) techniques and an onboard loran-C receiver.

Two types of satellite fixes were available. The first type, the spacecraft system, used the following approach. The transmitter data were collected by the

spacecraft during an entire orbit and were recorded on an onboard tape recorder. This information was telemetered to a ground station at Fairbanks, Alaska, and was subsequently relayed to the Goddard Spaceflight Center for computer processing. Position fixes were then available on computer tab forms after approximately 1 week.

The second type of satellite fix was available from the LUT, which is a real-time system and uses the satellite as a transponder (receiver/retransmitter). The transmitter data are reflected by the satellite to the LUT at Goddard which, using the self-contained minicomputer, calculates the platform position. Data are available by phone within 2-4 hours after satellite overpass.

Results and Discussion

The days immediately following the release were thought to be critical in terms of the operation of the transmitter, as well as Dianne's acceptance of it. Thus, we felt special concern when few radio transmissions to the satellite were received. Table 1 summarizes the dates Dianne was located by the three tracking systems: Aircraft tracking, NASA's LUT, or the spacecraft. As indicated, only five satellite positions were obtained during the last 2.5 months of 1979. Dianne's

position was determined from aircraft three times in October and three times in November. There was great concern in November when no satellite receptions were obtained. Then, for unexplained reasons, good satellite tracking information began in January 1980 and recorded until 15 June, when the transmitter was recovered from the beach 30 miles west of Port Arthur, Tex. During the full 8-month period, satellite fixes were obtained on 35 days out of 60 days on which the transmitter operated (58 percent successful). Dianne's position was obtained during the same day by both the spacecraft and the LUT on only three occasions, so the two systems seem to complement each other with minimal duplication.

Dianne's migratory route across the northwestern Gulf of Mexico is charted in Figure 3. She remained in the vicinity of Chandeleur and Breton Islands during October and November. In mid-December, she moved southward around the mouth of the Mississippi River and then westward approximately following the 10-fathom depth contour into Texas waters. She paused briefly offshore from Galveston during late January or early February. On 11 February, with the aid of a U.S. Coast Guard helicopter, visual contact was made with Dianne and photographs were taken of the turtle with the attached transmitter (Fig. 4).

Dianne continued her track southward to an area off Corpus Christi, Tex., where she remained from mid-February to mid-April. Her southernmost location was within about 30 miles of Brownsville, Tex. After April, she began to move

Table 1.—Dates on which loggerhead turtle "Dianne" was located by the three tracking systems.

Date	Aircraft	LUT	Spacecraft
1979			
October	17 18, 25	20, 28	24
November	5, 15, 29		
December			15, 31
1980			
January		12, 28	4, 12, 16, 24
February	1 11	1, 5, 13, 17, 21, 29	1, 9, 21
March		8, 20, 24, 28	12, 16
April		1, 5, 13	17, 21, 29
May		7, 23	19, 31
June			4, 8

northeast to a position about 10 miles off Port Arthur, Tex. Two consecutive satellite fixes indicated that the transmitter was on the beach about 30 miles west of Port Arthur. After a 1½-week period, during which no positions were obtained, we began to receive data indicating that the transmitter had moved inland approximately 500 miles to a small town named Galena, Kan. It was later learned that the transmitter had been found on the Texas beach by a man vacationing there. He had returned home to Kansas with the transmitter and later returned it to us with the report that the attaching lanyard had “obviously been cut” and there was no indication what might have happened to the turtle.

The transmitter was photographed on return and is shown in Figure 5. The braided lanyard had unravelled by this time, but the transmitter was otherwise in perfect operating condition.

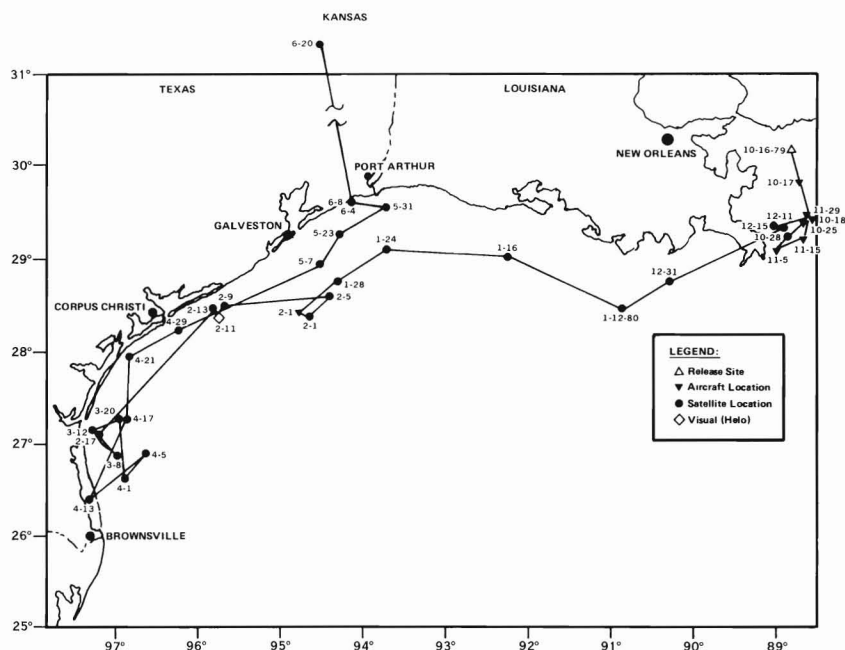


Figure 3.—Dianne's track in the Gulf of Mexico.



Figure 4.—Dianne as photographed from the U.S. Coast Guard helicopter.

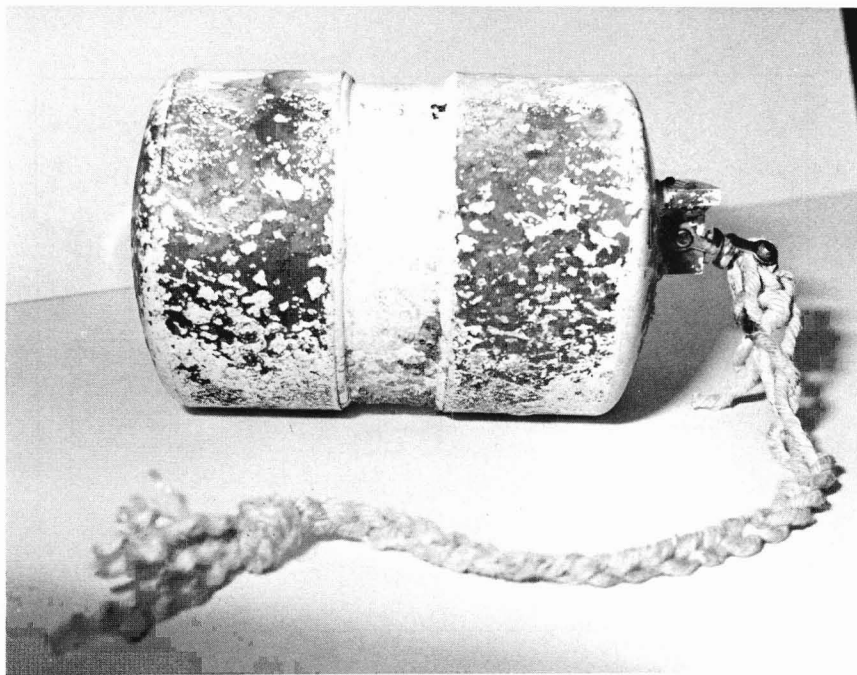


Figure 5.—Dianne's recovered transmitter.

Conclusions

The proximity of the coplanar antenna to the surface of the water apparently did not distort or otherwise preclude adequate radio transmissions to the satellite. However, no explanations are available for the lack of satellite messages during 1979, other than the turtle's activity and sea state. There was turbulent, windy weather during this period which could have caused the transmitter to be awash and thereby interfere with radio transmissions, but the turtle was obviously at the surface part of the time because she was located from tracking aircraft.

We can offer no explanation as to why

the spacecraft and the LUT receiving systems seldom provided location data on the same days. In fact, "same-day" fixes from both systems occurred only 9 percent of the time. A total of 19 positions were obtained by the spacecraft and 18 by the LUT. In summarizing the data, we find no apparent correlation between the reception time of day, number of received messages per satellite pass, or the number of successively received pulses. These data can be made available to researchers upon request.

The success of this turtle tracking experiment should provide an impetus for researchers to develop satellite-compatible electronics for other marine life. The obvious design problems for

many sea animals are that they spend little time near the surface, the timing for the transmitted signals will be critical, and it will take creative engineering to develop suitable transmitting antennas and attachment methods. Certainly we would project that the development of satellite tracking equipment for marine research will require a significant investment in money and manpower.

Acknowledgments

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