OCS Study
MMS 91-0069

APPLICATION OF REMOTE SENSING METHODS FOR TRACKING LARGE CETACEANS: NORTH ATLANTIC RIGHT WHALES (*Eubalaena glacialis*)

FINAL REPORT - FEBRUARY 1992

Contract No. 14-12-0001-30411

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For: U.S. Department of the Interior
Minerals Management Service
Alaska and Atlantic OCS Regional Offices

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ABSTRACT

Despite more than 50 years of protection from commercial whaling, the North Atlantic right whale (Eubalaena glacialis) continues to be the most endangered of the large cetaceans. There are only an estimated 350 right whales remaining of which 70% are scarred from fishing gear entanglement and ship collisions. This research used satellite-monitored radio tags to study the movements and dive habits of right whales inhabiting the Bay of Fundy (BOF) in the early fall, and determined whether tagging had noticeable adverse affects on the whales.

Satellite tracking is a powerful tool for studying free-ranging animals and has reshaped much of what we know about right whales. They were previously thought of as a slow-moving and nearshore species. From this study, we know that right whales can dive to 200 m routinely, can travel long distances over short time periods, sometimes at high speed and travel reasonably far from shore (500 km) into deep (4000+ m) water. There was no coherent migration observed. Individual right whale movements were quite variable. This study provided more specific detail on the movements and round-the-clock dive patterns of right whales than any previously reported.

Seven North Atlantic right whales were tagged and tracked during 1989 and 1990 in the BOF with satellite-monitored (Argos) radio transmitters. These whales traveled at least 9,590 km between 366 locations. In 43 days, one female and her 7-month old calf traveled 3,800 km, while an adult male traveled 3,000 km (although along a different track). All three whales returned to the BOF, changing our previous notion that multiple seasonal sightings are an estimate of the residency time in the BOF. Tagged whales moved both nearshore and offshore. Some movements were associated with oceanographic features including temperature gradients, upwellings, eddies and warm core rings (WCR). These features may have stimulated local primary productivity or resulted in concentrating the density of prey. Surface active breeding groups (SAGs) were common south of Nova Scotia, and many animals moved the 160 km between the BOF and this area within two days. A preference for traveling along the 200 m contour of the continental slope may have increased the whales' risk of collisions with ships. Individual whales averaged 30 - 113 km/day (1.3 - 4.7 km/hr.) with an overall average of 3.7 km/hr. for all whales combined. Surprisingly, speeds as high as 10 km/hr. were recorded; some of these were associated with currents in the same direction. The fastest whale was a pregnant female (Knowlton and Kraus, pers. comm.) who spent more time at the surface (33%) than any other whale. This whale also reported prolonged periods at the surface during 69% of its transmissions.

Data were collected from 92,963 dives. Dives averaged 86 $\pm$ 48 seconds. Whales were submerged most of the time ($\bar{x}$ = 78 $\pm$ 13%) although some individuals spent long periods at the surface. The shortest dives occurred from dusk to midnight and the longest dives occurred from midnight to dawn. The deep-scattering layer is nearer the surface during both these periods than during daylight hours. There were substantial

differences in dive patterns among individual whales. In 43 days of monitored dives, one adult male dove twice as frequently (with dives that were half as long in duration) as the comparable female with a calf. It was not possible to simply attribute the observed differences in dive patterns to the sex, age, reproductive or behavioral status of a whale.

One tagged male was equipped with a pressure sensor for 22 days. He dove routinely to the bottom in waters up to 200 m deep and had a maximum dive depth of at least 272 m. We observed whales surfacing with mud on their dorsum in water 200 m deep confirming dives to the bottom. As copepods may be distributed anywhere from the surface to the bottom, this deep diving may be both searching and feeding activity.

There was little reaction to tagging. Mild swelling at the tag attachment site was seen up to 3 days after tagging. A tagged female with a calf was tracked for 43 days and observed 16 days after tag loss, still with her calf. We saw no evidence of unusual scars or swelling after tag loss. We believe that tagging does not cause serious stress or pose a serious health risk to right whales.

INTRODUCTION

Despite more than 50 years of protection, the North Atlantic right whale (Eubalaena glacialis) continues to be the most endangered of the large cetaceans. In their introduction to the "Right Whales (Eubalaena glacialis) in the Western North Atlantic: A Catalog of Identified Individuals," Crone and Kraus (1990) describe the population and its known distribution as follows:

> "The North Atlantic right whale (Eubalaena glacialis) is now the rarest of the large whales. Current estimates indicate that no more than 300 - 350 survive along the eastern coast of North America. Sightings have been reported from as far south as the Gulf of Mexico, and as far north as Iceland, but most of the population is apparently distributed between Nova Scotia and Florida. Major aggregations have been described in the Great South Channel and Cape Cod Bay from late winter to early summer (Schevill et al., 1986; Winn et al., 1986), and in the Bay of Fundy (Gaskin, 1987; Kraus et al., 1982) and on the Nova Scotian shelf (Stone et al., 1988) from early summer to late autumn. Winter distribution for most of the population is unknown, but the primary winter calving ground appears to be the coastal waters between Savannah, Georgia, and Cape Canaveral, Florida (Kraus et al., 1986, 1988)."

Because there is interest in the development of offshore oil and gas resources within the known range of right whales, the Minerals Management Service (MMS) Environmental Studies Program funded this study to develop satellite-monitored radio tags to examine the movements, habits and habitats of the North Atlantic right whales. The resulting tag is to be subsequently used on bowhead whales in the Beaufort Sea.

The main objectives of this contract were to: 1) develop a satellite-monitored radio tag for use on right whales; 2) tag up to 10 right whales; 3) periodically relocate, observe and examine tagged whales in order to assess the accuracy of locations and evaluate the performance of the tag and deployment mechanisms; 4) provide photo documentation of the attachment methods and possible effects of the tag on the animal's physical well being and behavior; 5) document right whale movements including residency times, migration pathways, timing and speeds; and 6) relate the location of animals to known habitat characteristics and locations of other tagged whales to identify habitat preferences.

This report reviews the development of the tags and the resulting data obtained from satellite-monitored right whales during two field seasons: August - October 1989 and August - September 1990. The largest part of this report is the "Results" section which analyzes the biological data (Contract Task J, Monitoring and Analysis) and is divided into six major categories: 1) transmitter attachment; 2) transmitter performance; 3) locations and movements with an analysis of location depths, dive depths, and traveling speeds; 4) diving behavior including number of dives, dive durations, time spent submerged and surface resting behavior; 5) the relation of speed and respiration parameters; and 6) oceanographic factors including structures such as fronts, eddies and upwellings detected from sea surface temperature images and temperatures reported by the tag itself. A conclusion section discusses the major results of the study and is followed by a list of recommendations including tag modifications proposed for the bowhead whale study.

The Minerals Management Service contract allowed Oregon State University (OSU) to develop a surface-mounted tag (barnacle style) and/or an implantable tag (capsule style). Until recently, battery and transmitter size constraints made an implantable tag unlikely, therefore, our efforts were focused on surface-attached tags (Task A).

METHODS

The 1989 - 1990 study area is shown in Figure 1. The Right Whale Consortium sighting histories of all tagged whales may be examined in Appendix C. All of the movements summarized in this report were by animals which were tagged immediately east of Grand Manan Island in the central Bay of Fundy. A graphic information system (CAMRIS) was used to produce most maps in this report.

The Argos Data Collection System

The Argos Data Collection and Location System (ADCLS) was used to track tagged whales during this study (see Mate and Harvey, 1982). It is the only truly remote (monitoring) system available to civilians which can locate transmitters by satellite. Argos transmitters, or "platform transmitting terminals" (PTTs), have individual identification codes and a minimum repetition rate of 60 seconds; we obtained special permission to increase our repetition rate to 40 seconds. Each PTT transmits at 401.650 Mhz and is located by Doppler shift. PTT messages can contain up to 256 bits of sensor data, although our messages contained only 64 bits to conserve power.

Argos receivers are on board National Oceanic and Atmospheric Administration (NOAA) sun-synchronous, polar-orbiting, TIROS-N weather satellites. Each satellite has four ARGOS receivers and is capable of monitoring up to 415 PTTs in a specific area. Because of the polar orbit, the number of orbits (passes) overhead varies by latitude. There are 28 orbits/day for latitudes greater than 75° and as few as six orbits/day along the equator (Figure 2). PTTs can only send information to the satellite when it is overhead. From a fixed point on earth, the satellites move from horizon to horizon in 8 -

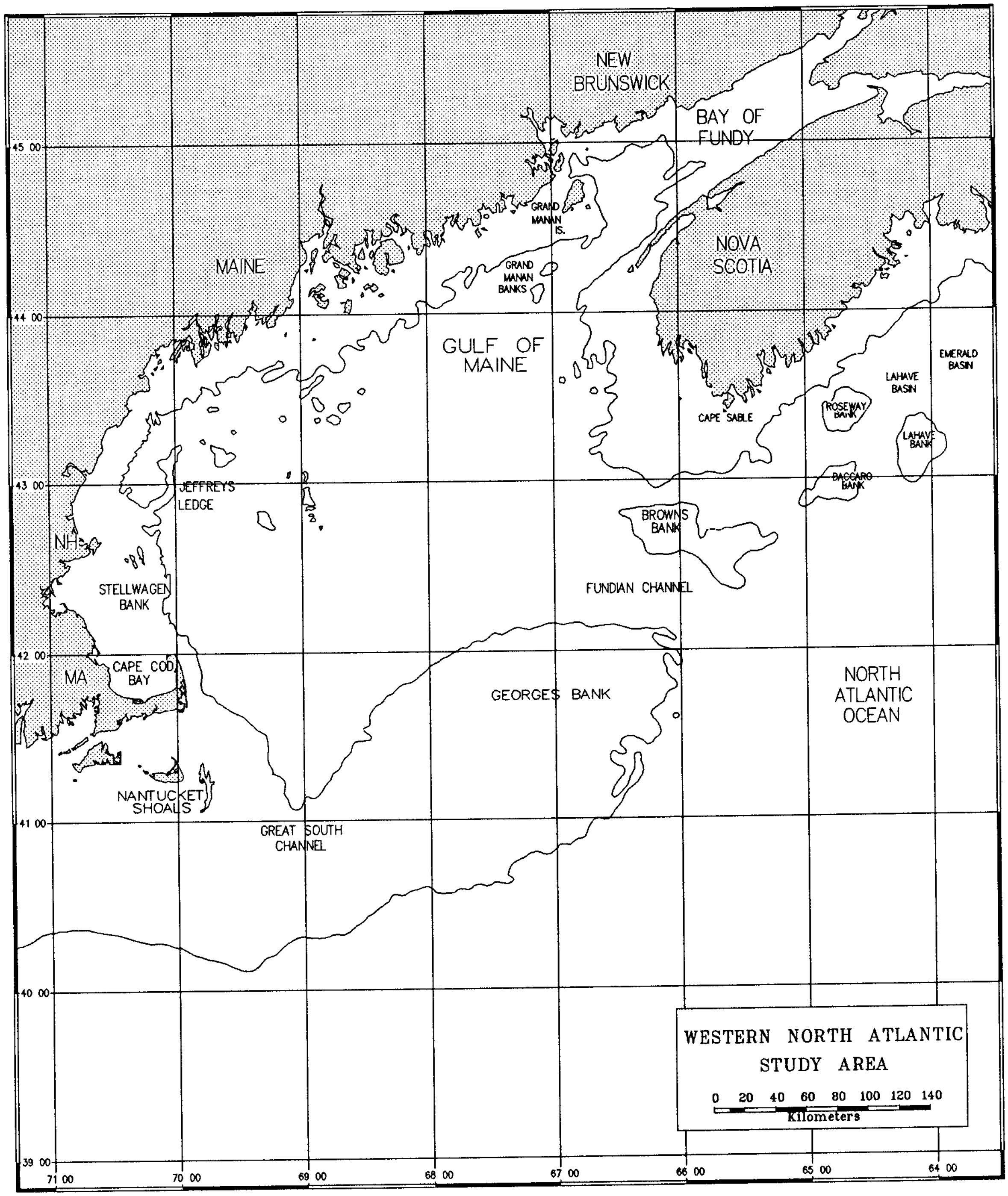


Figure 1. Map of 1989-1990 study area.

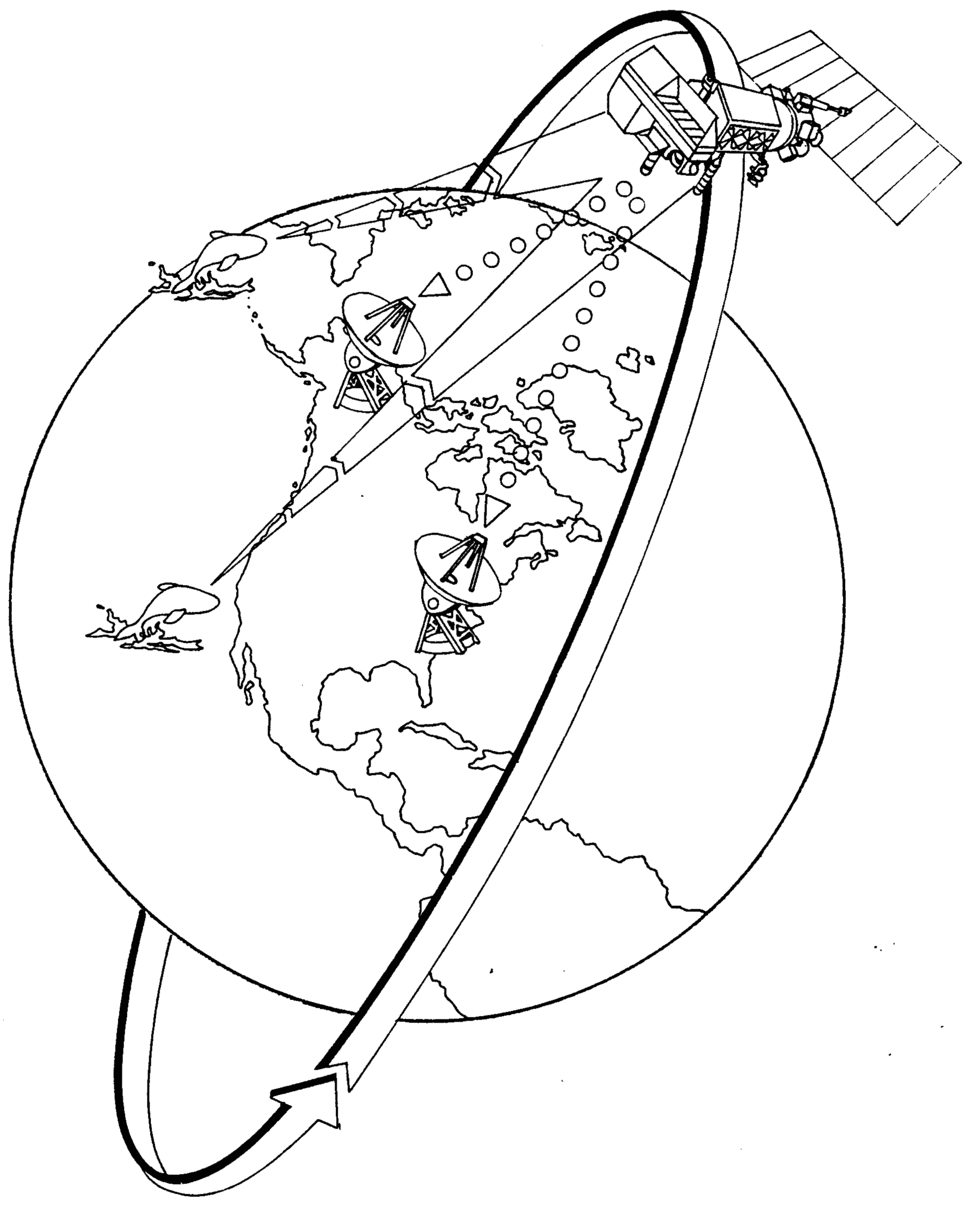


Figure 2. Representation of a NOAA TIROS-N satellite in polar orbit receiving transmissions from two different whales with Argos-monitored radio tags and relaying the information to ground stations at Wallops Island, Virginia and Gilmore Creek, Alaska.

Tag Design

Our tag housing and attachment design team consisted of Bruce Mate and Roderick Mesecar. Tag software was developed by Toby Martin and Walt Dillon. The MMS-sponsored workshop on cetacean radio tagging (Montgomery, 1987) was reviewed. We examined each of the previously successful VHF and HF conventional radio tag designs created by Goodyear (1981), Mate, et al. (1983) and Watkins, et al. (1981) in addition to the OSU satellite-monitored Argos work on pilot whales (Mate, 1989), manatees (Mate, et al., 1988) and humpback whales (Mate, et al., 1983). Individual tags and attachments were discussed with Tony Martin (Sea Mammal Research Unit, Cambridge, England), Kathy Frost and Lloyd Lowry (Alaska Department of Fish & Game), Joseph Geraci and Jeff Goodyear (University of Guelph), June Wilson-Hench and Larry Hench (University of Florida), Robert Hofman (Marine Mammal Commission) and Scott Kraus (New England Aquarium). From this research, it was determined that the design priorities were: 1) low profile to reduce drag; 2) a flexible base to conform to the curvature of the whale; 3) at least two attachments; 4) preferable use of bio-compatible materials; 5) good antenna orientation; and 6) ability to withstand pressure of 750 psi (500 m depth).

1989

After reviewing the certified Argos transmitters with their manufacturers, we chose the Telonics ST-3 as the most compact, durable and energy-efficient unit for the 1989 field trials. This unit also had an asynchronous serial port (a user interface), which allowed us to incorporate our own sensors and controller. We developed a microprocessor controller to provide onboard data management, collect temperature and pressure data from special sensors, interrogate a saltwater switch, coordinate transmissions with the satellite, and calculate a "cyclic redundancy check" (CRC) code to detect errors.

Housing

We decided that protection from pressure could most easily be accomplished by building the transmitter in a cylinder. The ST-3 transmitter measured 13.75 cm long by 7 cm wide by 1.5 cm high. These dimensions determined the 7 cm minimum diameter and 15 cm length of the cylinder housing. O-ring sealed endcaps housed the pressure and temperature sensors at one end, and the saltwater switch and a 16.5 cm flexible whip antenna at the other end. The remaining space was sufficient to accommodate six Altus C-cell organic lithium batteries and the OSU-designed microprocessor board.

Software

In 1989, we attempted to synchronize the PTT transmission cycle with satellite movements in order to use the PTT battery power as efficiently as possible. The orbital elements of the NOAA 10 and NOAA 11 satellites were determined using the Telonics

15 min. and are within reception range of a PTT for an average of 10 min. during each pass. The Argos system is administered by Service Argos which charges users by the number of days it collects data for each PTT. Information is retransmitted immediately and also stored on the satellite for later transmission to earth stations. The re-transmitted information can be received by local user terminals (LUTs), and positions can be calculated immediately. The stored information is downloaded from the satellite to one of three ground stations and then sent to the NOAA Data Concentrator in Suitland, Maryland before going into the user-accessible Service Argos computer.

Data were retrieved from Service Argos with an IBM PC-compatible computer and modem. In general, Argos-acquired locations were available within 3.5 hours of a satellite passing overhead. Because there is a LUT at Wallops Island, Virginia, which is part of the Argos system, some locations were available within 20 min. of a satellite pass. We also obtained monthly backup summaries from Service Argos on floppy disks.

Service Argos locations are categorized by location accuracy, which increases as the number of messages received and the time between the first and last message increases. Argos-determined location accuracies vary from unknown to $\pm$ 150 m. Table 1 summarizes the location class requirements and accuracies.

	REQUIRED CONDITIONS	ACCURACY
CLASS 3	* At least seven minutes between first and last message of pass * At least five messages received * Very good oscillator stability * Very good geometric configuration	Location accuracy: 150 m (1 st. dev.) (Varies with sunspot activity)
CLASS 2	* At least seven minutes between first and last message during pass * At least five messages received * Good oscillator stability	Location accuracy: 350 m (1 st. dev.)
CLASS 1	* At least four minutes between first and last message of pass * At least four messages received * Reasonable oscillator stability	Location accuracy: 1 km (1 st. dev.)
CLASS 0	* At least two messages received during pass	Quality of results, to be determined by user, depends on number of messages processed.

Table 1. Accuracy and required conditions for Argos location classes.

Prediction Program, and were used to calculate optimum transmission times for our Western North Atlantic study area. The programmed transmission period was twenty minutes, or almost twice the time it normally takes a satellite to pass from horizon to horizon, and thus allowed for animal movements of 3,000 km in any direction away from the initial tagging area. This synchronization of the transmission cycle with the satellite's movement had never been attempted by any Argos PTT manufacturer, and saved an estimated 60% of the transmitter's battery power. The resulting PTT had an operational life of approximately six months.

A 64 bit message was transmitted at each surfacing during the programmed twenty minute "transmit" cycle and included the following information:

Discrete Data (from the dive just completed):
- The duration of the dive ($\pm$ 2 s)
- The maximum depth of the dive ($\pm$ 17 m)
- The number of surfacings since the previous transmission (ITD)
- The water temperature ($\pm$ 0.5°C) at maximum depth

Summary Data (during a 4-hour summary period):
- The number of dives
- The average duration of those dives
- The maximum depth achieved during the 4-hour period

Other:
- Error detection (CRC) code for the discrete data

Dives were defined as a submergence of at least 6 s to avoid counting swells and splashes as dives.

The error detection (CRC) code was included because our 1987 pilot whale data (Mate, et al., in prep.) confirmed the experience of other Argos users that 8% - 15% of all messages contained transmission errors. Most buoy and balloon users of the Argos system repeat their messages because the information does not change quickly. This repetition allows them to easily detect transmission errors. Since we transmit unique messages (discrete information) regarding each dive, we needed an independent means of detecting errors.

Attachment

During the cetacean radio tagging workshop and subsequent discussions, Joseph Geraci made three specific recommendations: 1) increase the depth of the attachment; 2) immobilize the implant as much as possible; and 3) increase the surface area of the attachments as much as possible while minimizing the amount of damage to the skin surface area.

The sutures and "tynes" previously used for smaller tags appeared to be inadequate during blubber tests for the larger sized satellite-monitored tags. Thus, we considered alternatives such as: 1) sutures which had spiral shapes or formed large arcs to increase their surface area; 2) temple toggles (traditional-type harpoon heads) and folding barbs; and 3) devices which penetrated and then expanded, such as "molley bolts" and "catheters."

Eight prototypic designs for subdermal attachment of surface-mounted tags were considered. Each was developed in concert with appropriate delivery systems (Task "C"). The question of power to deliver and deploy tags was one of the most serious. A 1982 tag design for humpback whales (Mate, 1983) utilized a Holex pressure cartridge to hydraulically push stainless steel needles through curved forming fixtures. Similar designs which required bending materials were avoided because of the need for high power sources. We preferred pre-formed attachments, such as the modifications to the original barnacle tag design (Mate, et al., 1983) made by K. Frost (pers. comm.) for application to beluga whales. This design used pre-curved sutures which locked into place upon deployment. We experimented with three versions of these sutures, including some with fixed or folding barbs, to increase their surface area and resist outward migration.

The relatively large size of the tag resulted in significant hydrodynamic drag and exposed the tag to additional risk from rubbing on the bottom or against other animals. Thus, we felt a substantial subdermal anchoring system was required and settled on a spring-actuated system which deployed two curved stainless steel sutures to a depth of 10 cm - 12 cm. Ultimately, a flat piece of stainless steel 3 mm thick and 1.8 cm wide was added to the upper surface of the curved suture to increase the surface area and additionally resist the outward migration of the suture through what appeared to be very soft blubber. A spring (0.6 cm in diameter) was wound around the transmitter housing with a suture attached to each end (Figures 3a and 3b). The cylinder was mounted to a square base-plate with a foam rubber pad beneath it to protect the animal from abrasion. A "trigger" button in the center of the base was used to trigger the attachment when the base rested on a flat surface. The trigger released the energy of the coiled spring and installed the subdermal sutures in the skin and blubber. The tag was designed to be deployed either in a two stage process using a projectile dart and deployment vehicle, or from the end of a 5.2 m pole (as a backup system).

Deployment

The primary deployment system used a dart fired from a crossbow (Figure 4). A trailing line went through a pulley on the dart. One end of the line was attached to the crossbow, while the other end was attached to a "tag deployment vehicle." The deployment vehicle consisted of two 20 cm-diameter plastic net floats which had sufficient flotation for recovery of the tag if the line broke. Pulling the line drew the tag deployment vehicle to the dart on the whale. The tag could not attach until it reached the dart which "armed" the tag's trigger. The tag attached only when the tag was at the dart and the tag was flat enough on the whale's back to depress the trigger. Once the

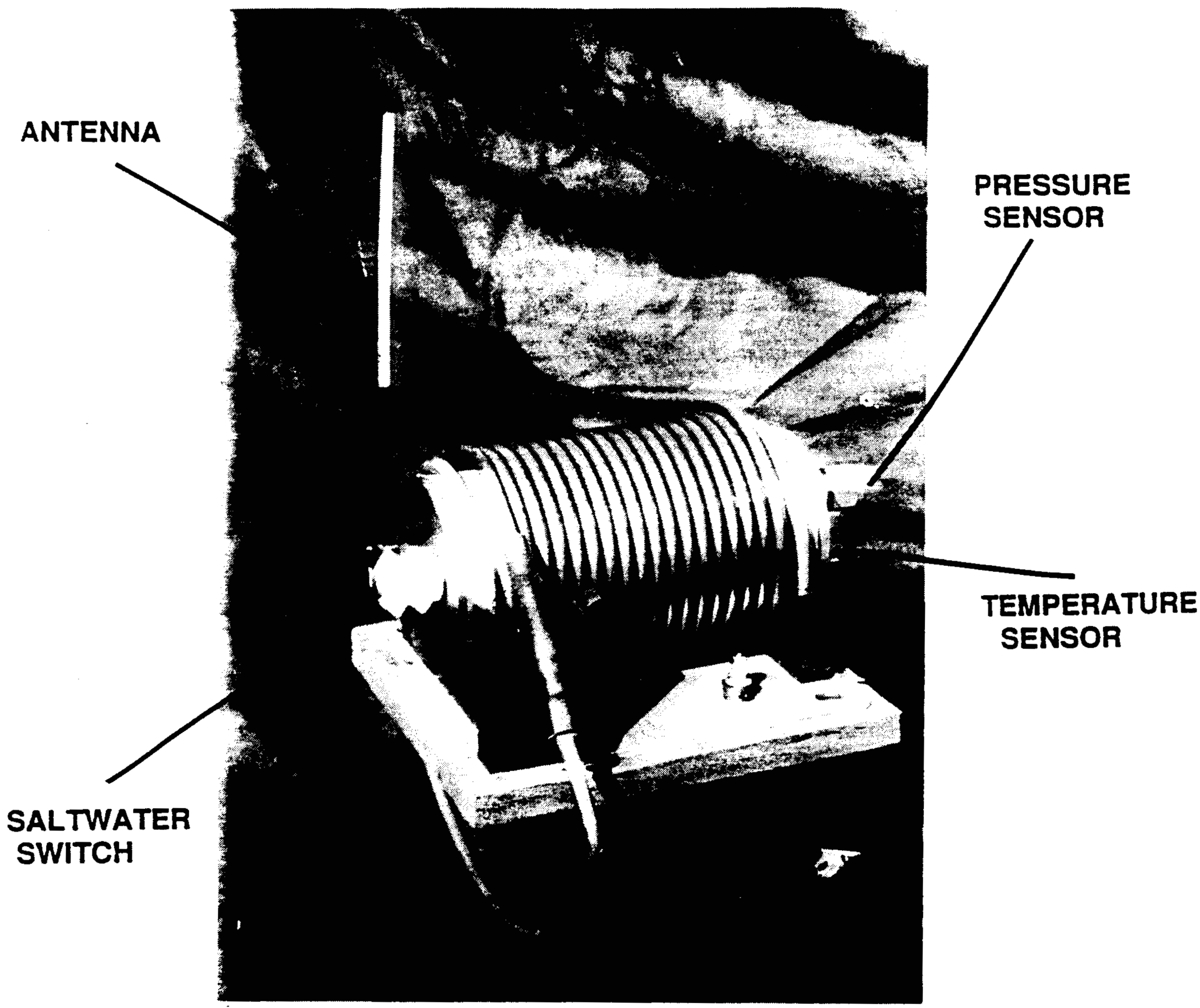


Figure 3a. The 1989 Argos-monitored radio tag for right whales, showing the spring-powered, subdermal attachments.

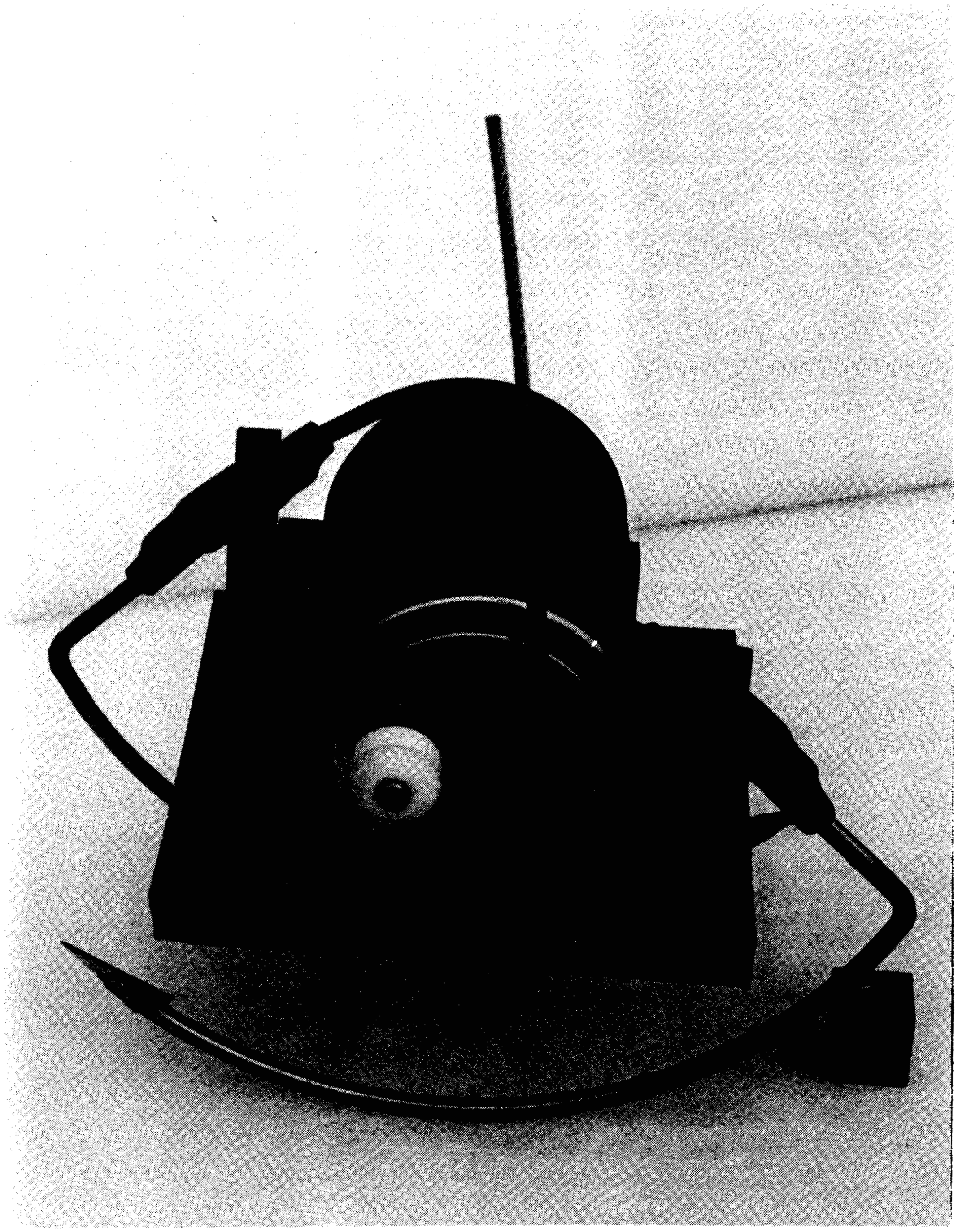


Figure 3b. The 1989 Argos-monitored radio tag for right whales, side view. Note: suture depth and angle as well as 1" cube for scale.

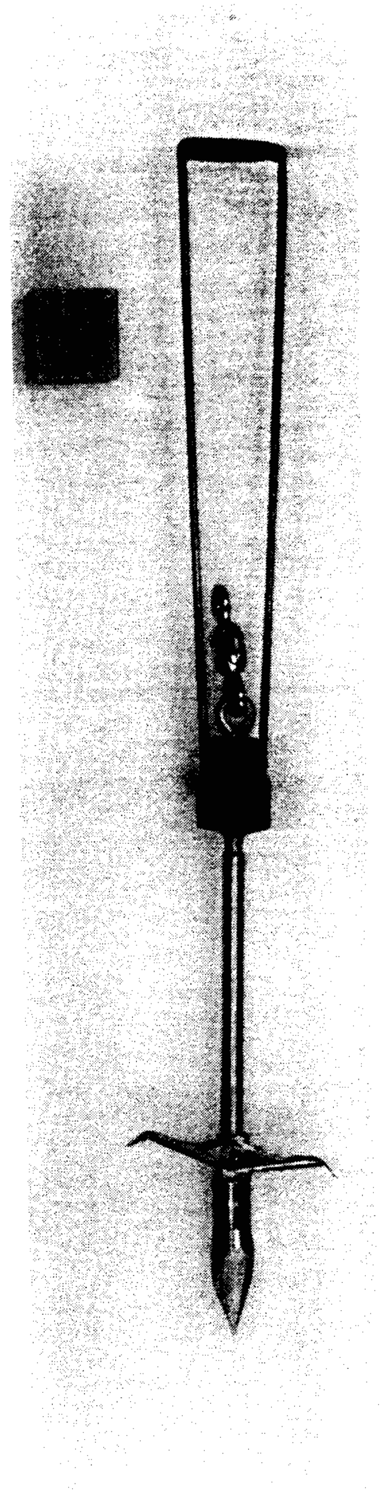


Figure 4. A crossbow-fired dart trailed a loop of line through a swivel. This allowed the tag to be pulled up to the whale for attachment if the dart location was suitable. **Note:** 1" cube for scale.

tag was attached, the deployment vehicle was released from the tag and could be recovered. If the dart was poorly located, deployment could be aborted by releasing the line attached to the crossbow.

1990

Because miniaturization had occurred since the 1989 season, we reappraised the available PTT packages including those by Roger Hill (Wildlife Computers) and Telonics. We decided to use the most compact transmitter, the new Telonics ST-6, which could also operate at a reduced power level. An evaluation of the 1987 pilot whale signal strength data determined that a 60% power reduction (from 1 watt to 400 milliwatts) would result in only a 10% loss in the number of messages received. This was fortunate as the Altus batteries we had previously used for higher power were no longer available. After testing an array of batteries, we settled on the Duracell 2/3A manganese dioxide battery which is small, reasonably priced and readily available because it is commonly used for photographic strobes.

We incorporated a small Telonics VHF radio transmitter into one end of the 1990 transmitter to relocate tagged whales and evaluate the accuracy of satellite-acquired locations (Task J). The VHF transmitters used different repetition rates on individual frequencies, and had an anticipated life of four months. The VHF tags were used to identify tagged whales at a range of several kilometers after satellite-acquired locations brought us into the general area. Thus, we knew which tagged whale we were observing without close approach.

Housing

The 1990 transmitter fit into a cylinder that was 5.6 cm in diameter and 12.5 cm long. It weighed 0.57 kg with attachments (Figure 5). This was a 66% reduction in volume and a 91% reduction in weight over the 1989 tag and allowed the entire transmitter to be applied as a projectile without the intermediate steps required in 1989. Drag was reduced by more than 80% because of both the tag size change and the significant loss of the attachment spring, stops and base-plate structure. At each end of the tag was a Delrin plastic endcap. Delrin was chosen to reduce weight, save machining time and function as an insulator for the antennae and saltwater switch.
The VHF and Argos antennae were mounted on opposite endcaps. The saltwater switch was located next to the Argos antenna.

Software

In 1990, the smaller Telonics ST-6 transmitters did not have software to precisely coordinate PTT transmissions with satellite passes. We decided to transmit two hours out of every six hours, and timed this transmission period to maximize satellite coverage. Because satellites have an orbit of 101 minutes, we knew at least one orbit would occur during each two hour transmission cycle. Figure 6 shows the four transmission periods

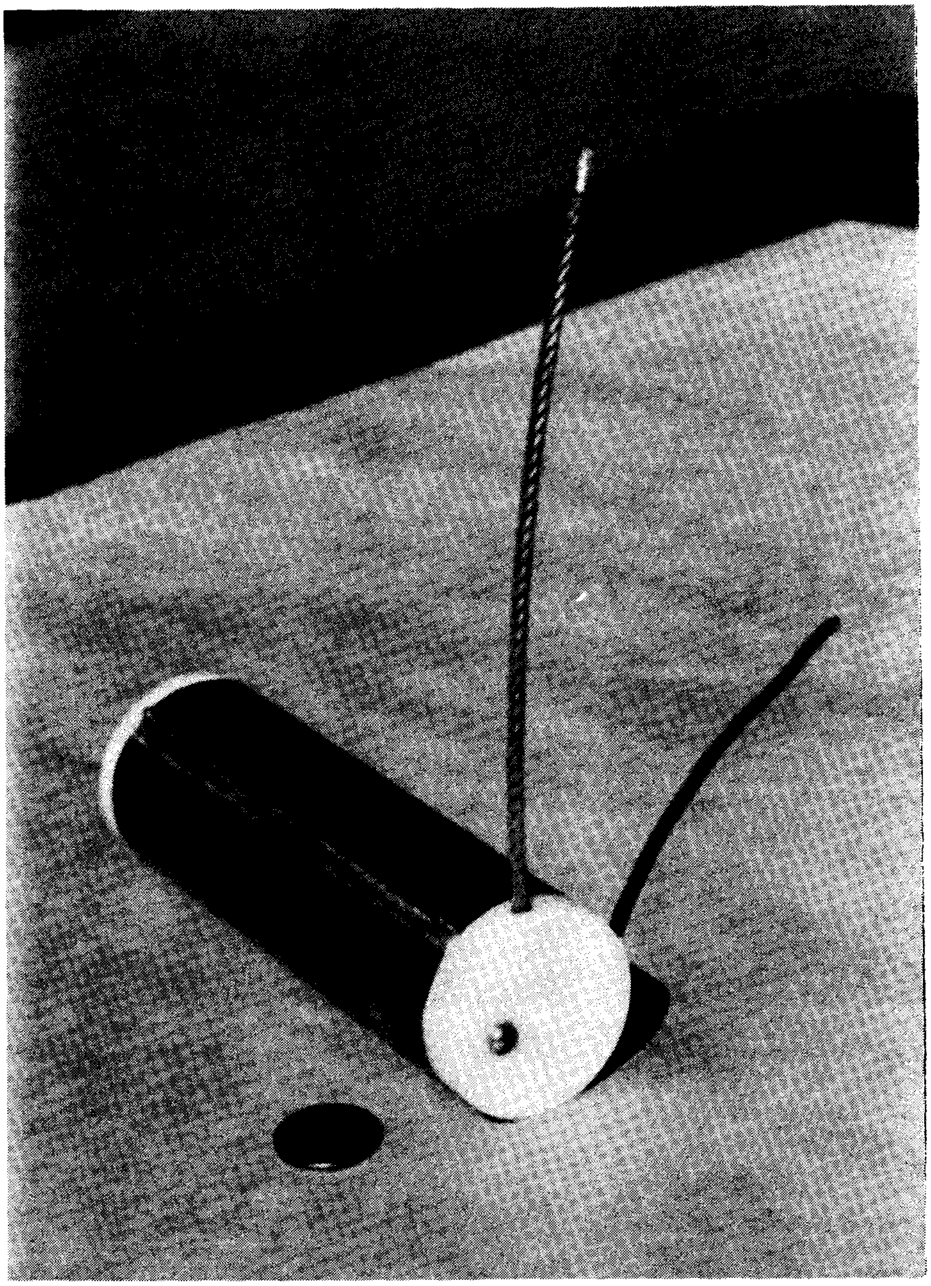


Figure 5. The 1990 Argos-monitored radio tag for right whales, showing the Delrin endcap with the antenna and saltwater switch. The final version had a second antenna for the VHF radio (see Figure 8).

and relates them to the local time (EDT), sunrise and sunset. The optimum PTT initialization time to maximize data recovery was calculated (Figure 7), and resulted in initiating the first transmission sequence of the day at 05:15 (GMT). Because the transmission schedule was fixed at two hours out of every six, the number of possible messages received throughout the day was different from 1989.

In 1990, the discrete information included the duration of the last dive, number of surfacings between transmissions and the internal temperature of the transmitter (Appendix B). Due to funding limitations, there was no pressure transducer for depth information. The temperature sensor was inside the transmitter and provided only an amorphous average of the animal's recent temperature environment. Nonetheless, deep dives into temperature-stratified water were detected when the PTT reported long dives associated with colder temperatures. Short dives near the surface reported warmer temperatures. Summary information included the number of dives and average duration of all dives during a 6-hour summary period.

Attachment

A stainless steel shaft, 6 mm in diameter and 14 cm long was mounted in each endcap. Since clean cuts heal faster than jagged cuts, a double-honed blade was used at the end of each shaft. Two pairs of folding barbs were mounted behind the blade (Figure 8). The cutting action of the blade reduced resistance to penetration allowing application with less power. One pair of barbs was in the plane of the entry blade and one pair was perpendicular.

Deployment

PTT performance was optimized when 1) the antenna was vertically oriented, and 2) the tag was well out of the water during each whale surfacing. Thus, we attempted to place the tag high on the back, approximately 1 m behind the blowhole. Close approaches were, therefore, required by our small boat to achieve proper antenna orientation and tag location. A modified Barnett 68 kg (150 pound) compound crossbow was used to accurately apply tags at distances up to 15 m. An aluminum shaft with a "C"-shaped tag holder fell away after tagging (Figure 8). Attention was devoted to velocity to avoid excessive impact and bruising by the tag. A bobbin-wound, 9 kg (20 lb) test line was used to recover the pushrod and tag if it missed its mark.

Ballistic Tests

Both the 1989 and the 1990 attachment systems were extensively tested on foam targets and gray whale skin and blubber to control accuracy, impact and antenna orientation. The gray whale samples were obtained from fresh carcasses found along the Washington and Oregon coasts. In both cases, testing determined necessary changes to the system and assured that the electronics and batteries would survive the application process.

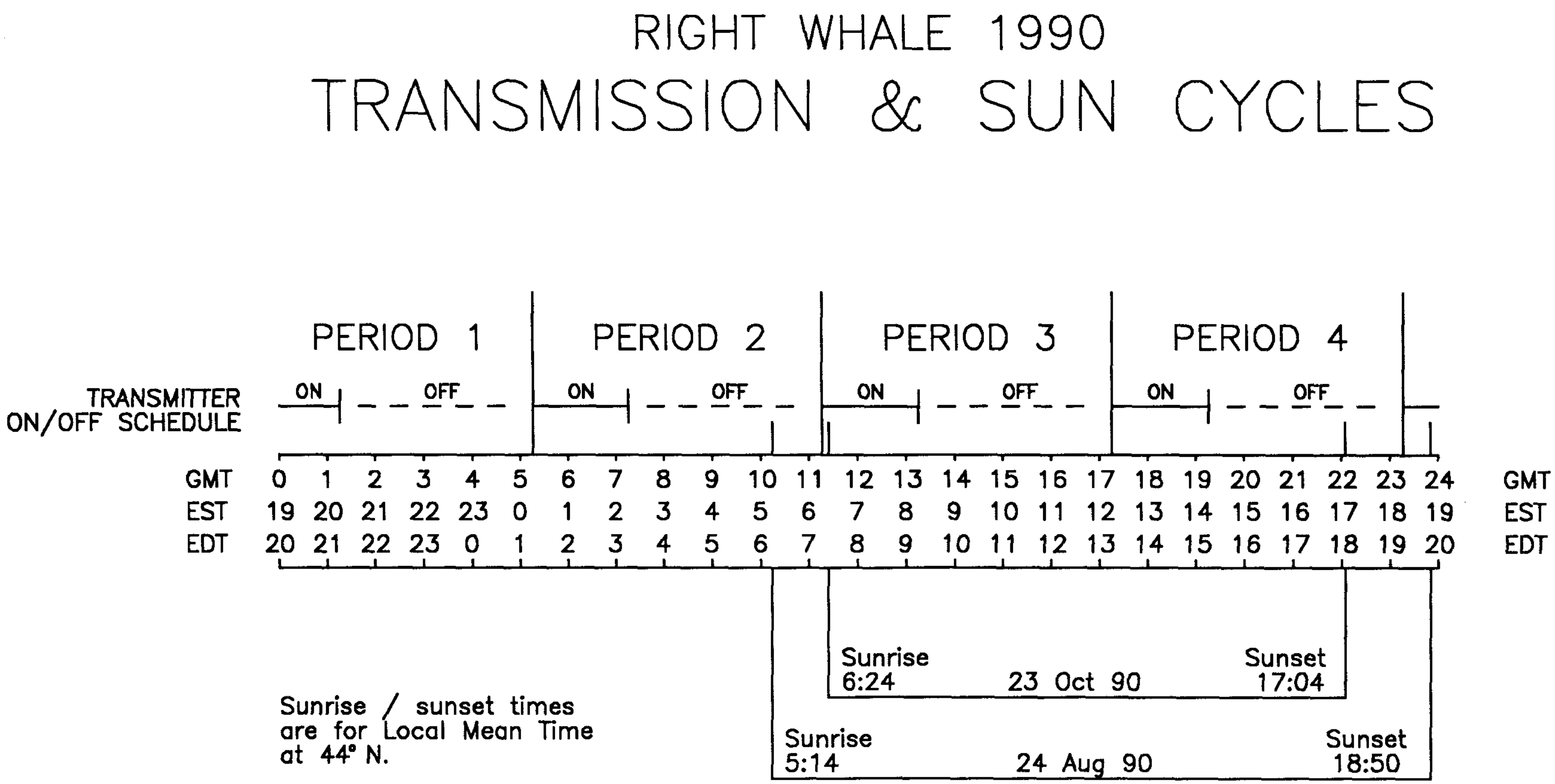


Figure 6. The daily schedule of 1990 6-hour summary periods and four, 2-hour transmission periods, showing Universal (GMT) and local time in relationship to sunrise and sunset.

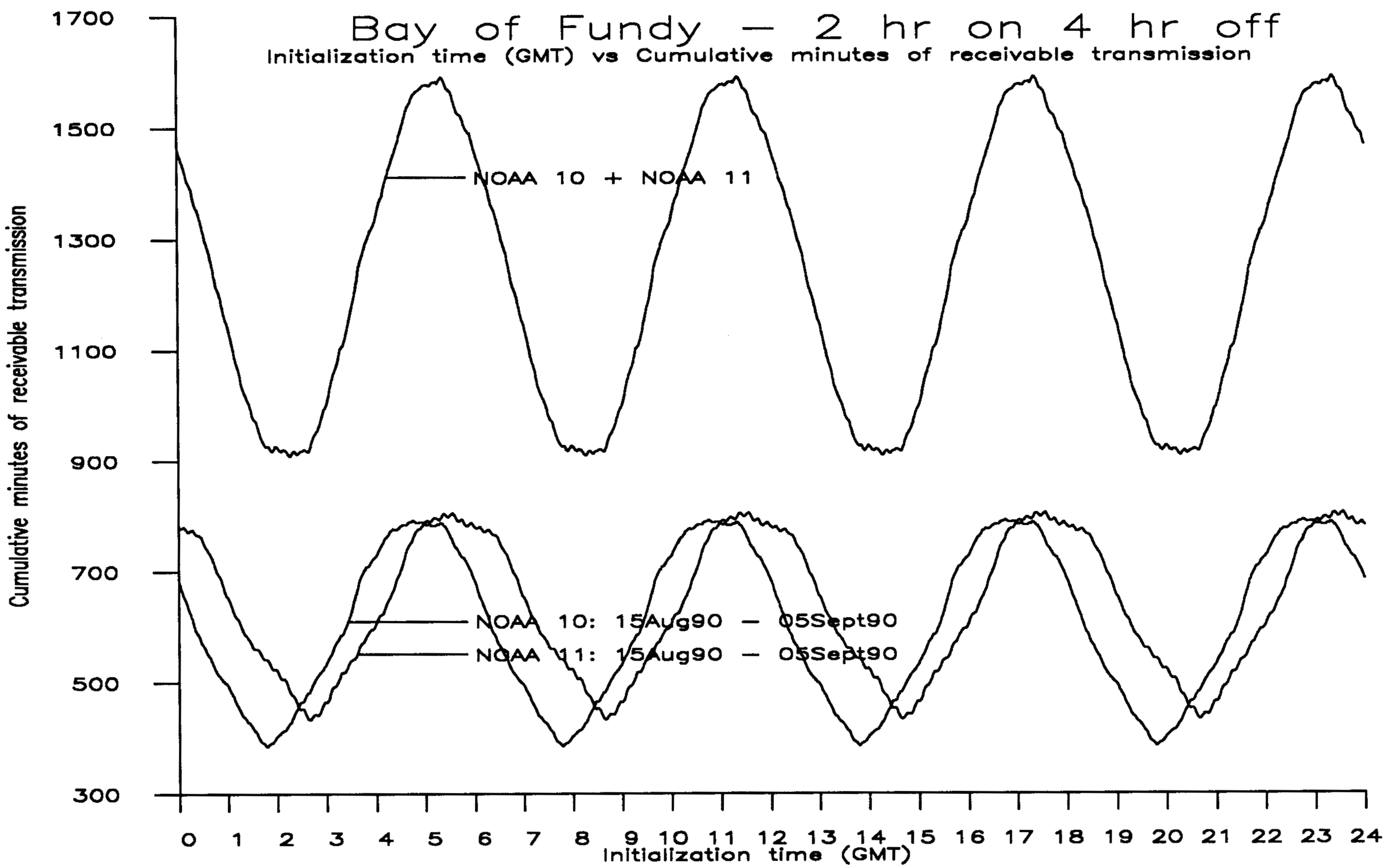


Figure 7. The effect of initialization time on the number of minutes satellites are overhead based on four evenly spaced two-hour transmission periods in the Bay of Fundy.

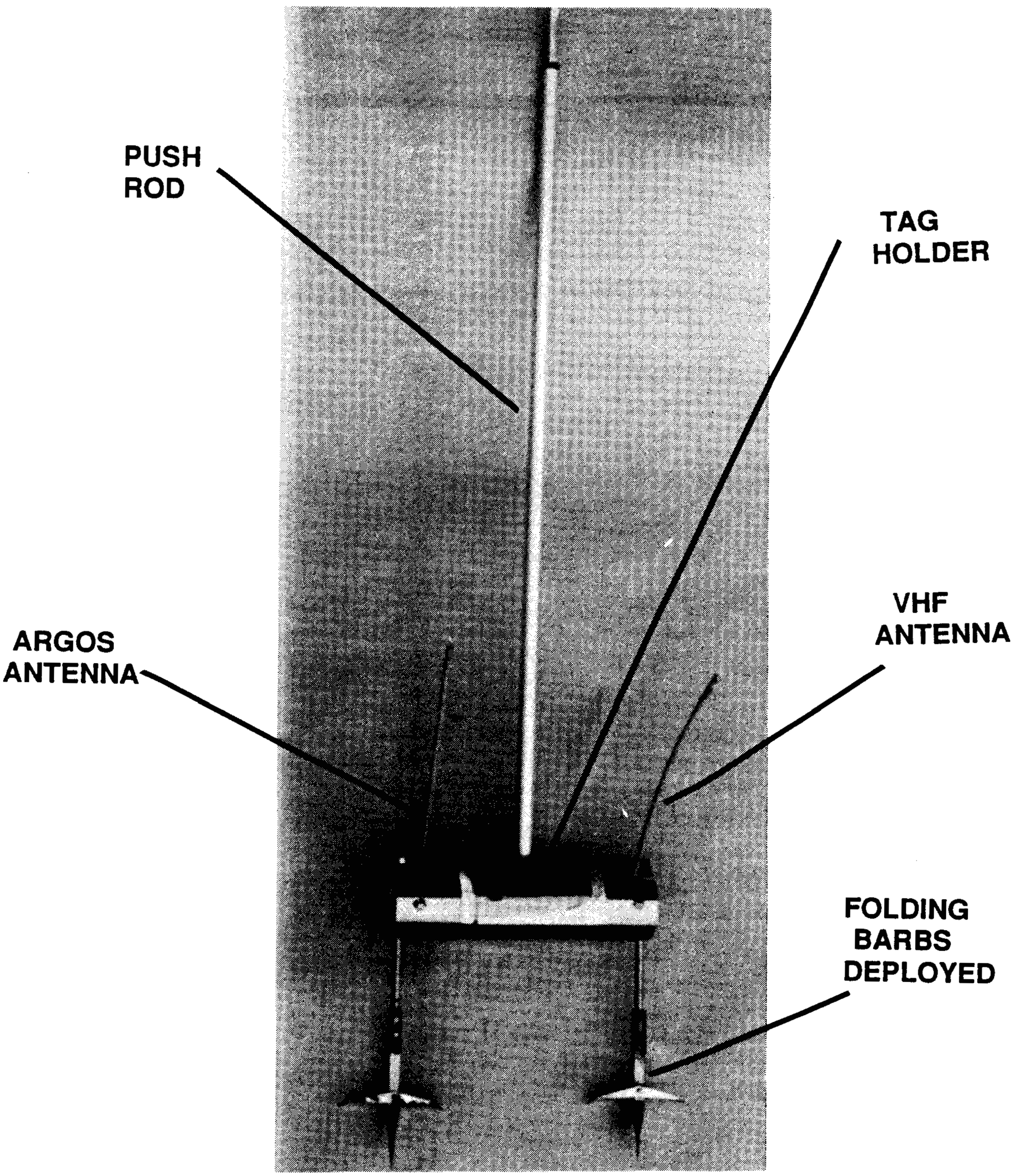


Figure 8. 1990 Argos-monitored radio tag as modified during the field season, with attachments on the extended housing rather than the endcaps. Attachments are shown with one pair of folding barbs in the "deployed" position. Push rod falls away after attachment.

Attachment Penetration Tests

The carcass tests determined the depth of penetration for subdermal anchors. Pull scales were used to determine how effective different barb designs were during carcass testing. These tests had some relevance to animals rubbing the tag on the bottom or other animals. We found no effective way to simulate the long-term effects of hydrodynamic drag which would predict the process of pressure necrosis for a live animal.

Transmitter Tests

Tests of transmitter location accuracy were conducted in seawater ponds at the Hatfield Marine Science Center (HMSC) at Newport, Oregon.

Bio-Compatible Materials

We reviewed tests of several metal and plastic materials for tissue bio-compatibility (Geraci, et al., 1990; Hench, 1980; Wilson and Merwin, 1988). HDPE, a material tested by Geraci, et al. (1990), showed promise for tissue adhesion but did not possess enough structural strength on its own to act as an attachment.

One potentially effective material which had not been tested on cetaceans was BioGlass^R which softens so that tissue can grow into it. In 1990, we conducted tests of BioGlass^R on a bottlenose dolphin at Sea World Orlando. The work was carried out under a NMFS permit in collaboration with Jack Pearson, Mike Walsh and Terry Campbell (Sea World Orlando) and Drs. Larry Hench and June Wilson-Hench (developers of BioGlass^R). BioGlass^R was used as a thin coating over five stainless steel pins which were inserted along the leading edge of the bottlenose dolphin's dorsal fin as per the protocol of Geraci, et al. (1990). Three pins came out of the animal within three weeks and were recovered from the pool. The remaining two were loose and removed. There was no BioGlass^R left on any of the pins. It appeared that the BioGlass^R coating was too thin on the implanted samples and entirely dissolved, leaving nothing to which the tissue could adhere. No long-term damage resulted from the application of these materials. The insertion holes were already closed on the days pin losses were noted. Re-pigmentation of the area was complete within one week.

Bottlenose Dolphin Test

In July 1990 we attached a 1990 right whale tag to a large, female bottlenose dolphin in Tampa Bay, Florida using a dorsal fin saddle attachment (Scott, et al., 1990). The dolphin work was conducted in collaboration with Randy Wells whose program continued observations on the behavior and movements of the dolphin. The tag was attached with Delrin pins which were designed to break away if they caught on anything. The pack came off 26 days after tagging. In addition to collecting interesting data, four important factors are worth noting: 1) it took only 15 minutes to apply the tag; 2) the tagging process caused no overt reaction from the animal; 3) the animal was resighted four to fourteen months after tag loss without holes or scarring on its dorsal fin; and 5) the dolphin was still in the company of her five-year-old calf whenever it was resighted (Wells, pers. comm.).

RESULTS AND DISCUSSION

Transmitter Attachment and Effects

1989

In 1989 we attempted to tag 37 animals during 22 days at sea. Thirty of the attempts were with the dart-pulley-deployment-vehicle system and resulted in three misses, nine darts bouncing off the animal, six darts pulling out, five lines being broken, and assorted failures of swivels and latches (Mate et al., in prep.). None of the dart-pulley-deployment-vehicle system attempts were successful in attaching a tag, but we did learn a great deal about the holding power of various dart configurations as a result of these attempts.

The first darts, which were similar to straightened fishhooks, had been tested extensively on samples of gray whale skin and blubber, as no right whale samples were available. In carcass tests, these darts withstood a 45 kg straight pull. When, in the field, these darts pulled easily out of right whales, we revised a folding barb design which we had also tested prior to the field season. This dart used a sharpened blade at its tip to ease penetration and provide some initial purchase for a folding barb. These darts held well enough to break lines rated at 240 kg and provided the basis for our confidence in redesigning the 1990 attachments.

Field studies revealed a number of areas in which our modelling of the situation had been inadequate. The two-stage attachment technique proved to be totally unsuccessful largely due to turbulence from tail flukes and drag which caused lines and swivels to break. The 1989 tag was relatively large and thus had considerable hydrodynamic drag. It might have been easier and possibly more successful to have eliminated the flotation of the deployment vehicle to reduce the drag. Because they were so easy to approach, we attempted to tag animals in surface active groups (SAGs). However, because multiple animals were rolling next to one another, lines became entangled and broke.

The pole technique was more successful. We tagged seven animals in seven attempts. A major factor in our late season success was the addition of Scott Kraus to our crew. His experience in maneuvering around right whales proved invaluable. However, none of the seven pole-deployed tags were attached well, and we observed tag losses one, two and three days after tagging. There were actually three versions of the subdermal attachment which evolved during the 1989 season as the result of the poor performance of each previous type. None of the tags deployed completely. Tests on carcasses after the field season revealed that we had been misled by tests in the lab on "detached" sheets of blubber. High resolution 8 mm video shot at a high shutter-speed was used to record the action and revealed the problem when played back at slow speed. The video showed that the high energy sutures actually lifted the blubber into a "wrinkle" before penetrating, which resulted in an attachment we could not achieve on a live animal. This action occurred so fast that it was invisible to the naked eye and went undetected in our earlier, normal speed video records of pre-field laboratory tests.

The single, limited success in 1989 was an adult male (PTT #843, NEA #1446) known as "Van Halen," which was tracked for 22 days. We believe this success was due in part to the modified attachment of the tag. One animal ("Admiral," NEA #1027) tagged in 1989 was observed in 1990 with a small, straight white scar. No other 1989 tagged animals have been resighted.

1990

We had little problem applying tags in 1990. Eight tags were applied in the first three days of the field season (see Figure 9). We used VHF signals to identify tagged individuals at a distance, and our New England Aquarium colleagues used callosity patterns and scars (Crone and Kraus, 1990) to confirm these identifications at close range. When we saw tagged animals, but did not hear a VHF signal, we made close approaches to document tag problems. The 6 mm stainless steel attachments were bent on at least two transmitters (by as much as 40 degrees) within two days. We do not know if the physical damage was caused by rubbing on other whales or on the bottom. However, as a result, a Delrin endcap was broken out of both cylinders, seawater entered the transmitter, and the batteries were shorted out. We confirmed endcap failures on two of the first eight animals we tagged. We used a modified design with attachments fastened to the cylinder itself to tag PTT #823 (NEA #1421). The modified tag transmitted for 43 days, matching the best of the eight original tags.

At the range most whales were tagged, the power of the crossbow appeared adequate. Some tags may not have deployed completely. It was difficult to tell because the resilience of the blubber may have allowed the tag to "bounce" back when the barbs opened. Deployment may not have been complete if the tag had a poor angle of application. It would be necessary to test tags on fresh, dead specimens to answer some of these questions.

Of the nine whales we tagged in 1990, we received data from seven and resighted five (Table 2). Only two had any swelling and both of these had obvious attachment problems. One whale (PTT #834, NEA #1248) was observed 8 days after tagging without its tag, but had one tyne still in the skin. The other (PTT #827, NEA #1941) was observed 6 days after tagging with one endcap pulled from the housing and the tag still attached by the other tyne. Both animals had swelling 1 cm - 2 cm high for a 5 cm radius around the attachments. The three other whales were resighted from 6 to 59 days

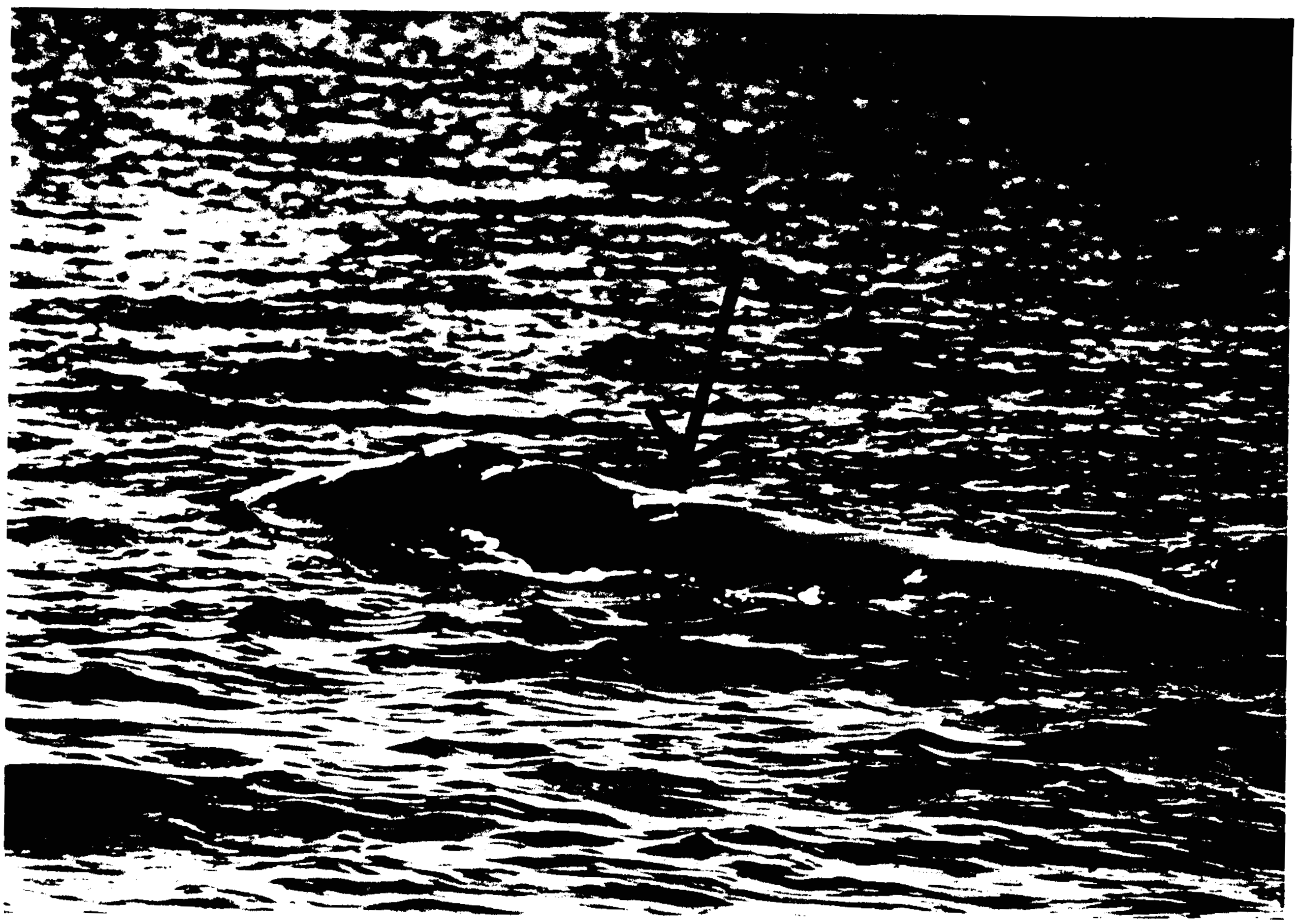


Figure 9. Whale (NEA #1981) with satellite tag (PTT #833) in 1990.

after tagging and showed no swelling whatsoever despite some attachments bending 60 degrees. "Wart" (PTT #839, NEA #1140) was seen 59 days after tagging (16 days after tag loss). There were no signs of swelling or infection and only a single 1 cm diameter white scar where the tag had been.

Loss of tags may be ascribed (at least in part) to: 1) tissue rejection of a foreign object, 2) high levels of vigorous breeding activity and, 3) females with active calves. We also saw evidence of bottom contact when whales surfaced with mud on their heads.

Transmitter Performance

In 1989 and 1990 there were no PTT electronic failures, and frequency stability (necessary for accurate locations) was very good. While the transmitters performed exceedingly well in general (see Table 2), transmitted data were subject to error. Errors can be induced by interference during transmission from the PTT to the satellite or from the satellite to an earth station receiver, and can distort individual bits or whole sections of the message. The resulting erroneous message may or may not have reasonable values and must, therefore, be confirmed by independent means. Summary data for each summary period were confirmed when we had multiple transmissions. Alternative strategies were used to confirm discrete information.

1989

In 1989 a CRC code was a part of each message and was used to determine errors in the discrete portion of the message (Appendix A). The CRC code was calculated by the microprocessor in the PTT and sent as a part of each transmission so errors could be detected easily. Figure 10 illustrates the number of messages received during each 4-hour summary period from PTT #843. This was the only 1989 PTT to achieve any long-term track. The transmission scheme (synchronization of transmissions with satellite passes) worked well for south-north passes, and resulted in a high number of messages between 1600 - 2400 GMT. However, a failure of the software to coordinate with north-south orbits resulted in very few data points between 0400 and 1200 GMT. A total of 304 messages were received for PTT #843, and of these 33 (11%) contained errors detected by the CRC code.

1990

Of nine whales tagged in 1990, two did not provide any useful data, while seven provided from 22 - 665 messages each for a total of 1,466 messages (Table 3). Individual PTTs operated from 3 - 43 days for a total of 160 "whale-tracking days." This body of information represents the largest data set available on dive durations, movements and long-term monitoring of any species of cetacean. In 1990, the Telonics ST-6 software did not include error detection codes. Instead, we checked to determine whether discrete dive durations were feasible and also used range limiters (see Appendix B). If any of the discrete or summary information was found to be in error, the entire line of discrete

PTT#	NEA#/NAME	STATUS	TAG DATE	TAG TIME	FIRST MESSAGE	LAST MESSAG	TAG DAYS	RESIGHTED	TAG CONDITION
843	#1146 VAN HALEN	ADULT MALE	15 OCT 89	15:16 Z	15 OCT 89 17:57 Z	5 NOV 89 19:27	22	NO	
823	#1421 WILLIE	ADULT MALE	12 SEP 90	118:35 Z	12 SEP 90 23:48 Z	24 OCT 90 21:12	43	NO	
825	#1629 IPANEMA	ADULT FEMALE + CALF	26 AUG 90	19:49 Z	28 AUG 90 18:05 Z	6 SEP 90 06:36 Z	10	30 AUG 90[1]	TAG ON;1 TYNE IMPLANTED;NO CALF
								31 AUG 90[1]	SAME AS ABOVE
								1 SEP 90[1]	TAG REIMPLANTED; NO SWELLING;WITH CALF
827	#1941	'89 CALF FEMALE	26 AUG 90	18:18 Z	26 AUG 90 23:36 Z	28 AUG 90 18:06 Z	3	1 SEP 901	TAG ON; ENDCAP OFF; SLIGHT SWELLING
831	#1152 NECKLACE	ADULT MALE	24 AUG 90	17:30 Z	25 AUG 90 05:27 Z	8 SEP 90 12:19 Z	15	NO	
833	#1981 "JJ"	JUV ?SEX	25 AUG 90	22:09 Z	26 AUG 90 00:00 Z	6 SEP 90 13:05 Z	12	27 AUG 90[1]	RAISED 1.5" OFF BODY
								30 AUG 90[1]	BOTH TYNES BENT 60^0
								31 AUG 90[1]	SAME AS ABOVE
								1 SEP 90[1]	SAME AS ABOVE; NO SWELLING
834	#1248 RUDOLPH	ADULT FEMALE	24 AUG 90	20:21 Z	25 AUG 90 05:28 Z	27 AUG 90 13:29 Z	3	27 AUG 90	TAG ON; SLIGHTLY RAISED
								1 SEP 90	NO TAG; 1 TYNE STILL ATTACHED; SWELLING
835	#1127 DASH	ADULT FEMALE	25 AUG 90	21:35 Z	---	---	0	NO	
839	#1140 WART	ADULT FEMALE + CALF	24 AUG 90	19:19 Z	25 AUG 90 00:24 Z	5 OCT 90 08:05 Z	42	10 SEP 90[2]	TAG ON
								10 SEP 90[3]	TAG ON
								21 OCT 90[4]	NO TAG
840	#1135 STRIPE	ADULT FEMALE	24 AUG 90	20:00 Z	25 AUG 90 00:24 Z	31 AUG 90 17:34 Z	7	4 AUG 91	NO TAG; WITH CALF

RESIGHTED BY: 1. NEA/OSU (NEW ENGLAND AQUARIUM/OREGON STATE UNIVERSITY), 2. CCS (CENTER FOR COASTAL STUDIES), 3. PMMRC, 4. BIOS

TABLE 2. Summary of monitored right whales during 1989-1990 with resighting dates and tag conditions.

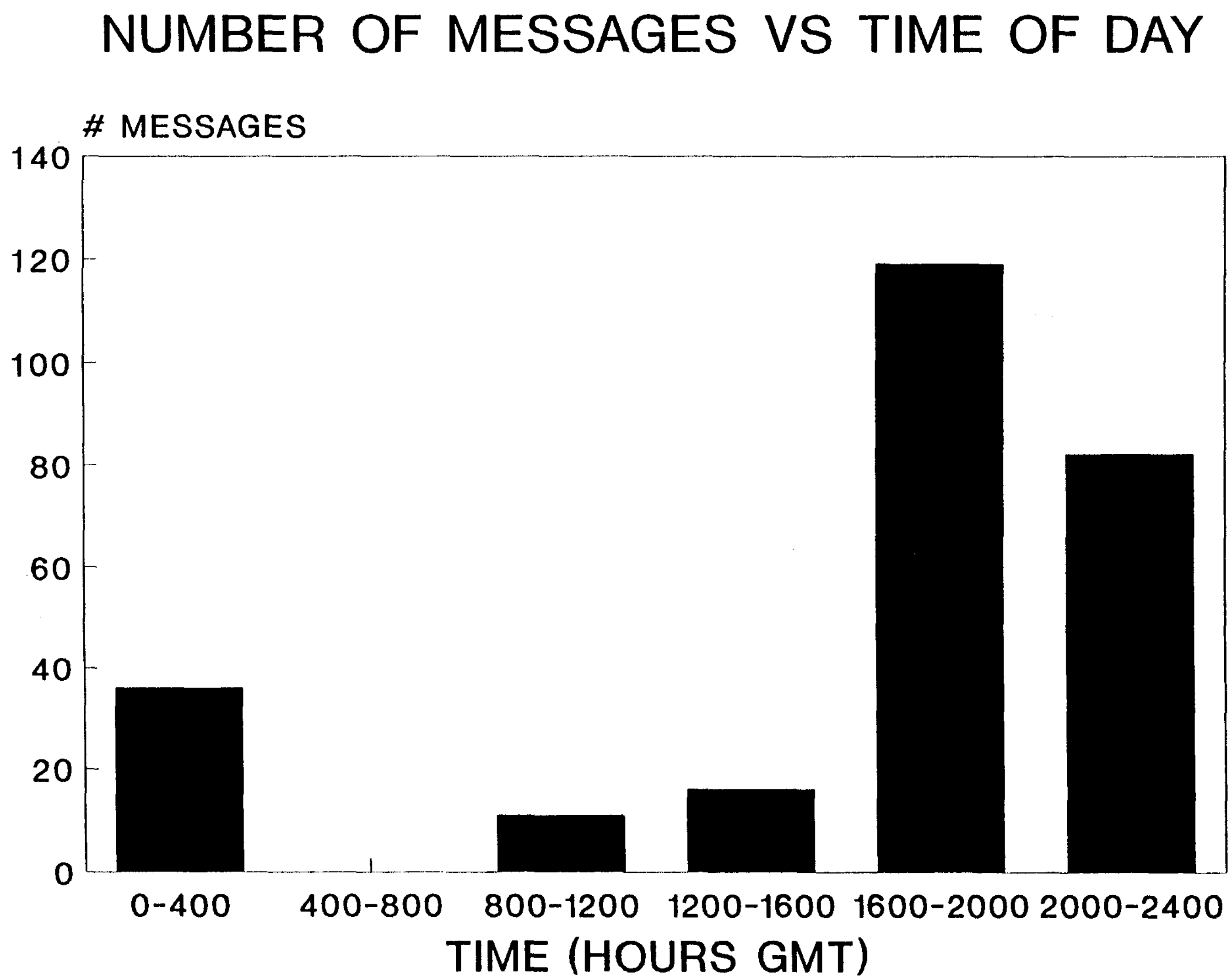


Figure 10. Frequency histogram of the number of transmissions received during each 4-hour summary period for PTT #843 (1989).

**TABLE SUMMARIZING RIGHT WHALE 1989-1990
SATELLITE TELEMETRY SEASON**

PTT#	TOTAL TAG DAYS	TOTAL # MESSAGES	TOTAL # LOCATIONS	TOTAL # DIVES	DISTANCE TRAVELLED (KM)
843 ADULT MALE	22	297	71	12,209	1,523
823 ADULT MALE	43	665	136	47,591	3,030
825 ADULT FEMALE + C	10	30	7	1,510	302
827 JUV. FEMALE	3	22	----	630	-------
831 ADULT MALE	15	23	NONE*	1,399	-------
833 JUV. ? SEX	12	112	26	4,981	576
834 ADULT FEMALE	3	4	0	NA	NA
835 ADULT FEMALE	0	0	0	NA	NA
839 ADULTFEMALE + CALF	42	528	111	22,273	3,833
840 PREGNANT FEMALE	7	86	15	2,370	793
TOTALS	154	1,763	366	92,963	9,590

* NO LOCATIONS DUE TO ARGOS ERROR

TABLE 3. Summary of duration, messages, locations, dives and minimum distances traveled for right whales tagged in 1989 - 1990.

"sensor" data was discarded. The error rate by period is shown in Table 4.

	# TRANS-MISSIONS	ERRORS	ERROR RATE
PERIOD 1	228	50	22%
PERIOD 2	460	86	19%
PERIOD 3	445	72	16%
PERIOD 4	333	77	23%
ALL PERIODS	1466	285	19%

TABLE 4. Error rate, by period, for the 1990 6-hour summary periods.

The highest error rates occurred from mid-day to midnight (Periods 4 and 1) and the lowest rate occurred from sunrise to mid-day (Period 3). The overall error rate of 19% is somewhat higher than that experienced by other Argos ocean users (15%) possibly because their buoys have stronger signals, larger batteries and larger antennae. The National Data Buoy Center (NDBC) has experienced error rates averaging 15% (Ray Partridge, pers. comm.). The NDBC performed direct monitoring tests using a local user terminal (LUT) and determined that most of the errors are induced after earth stations have received the downlinked messages from the satellites. Each re-transmission of the message adds additional risk of creating errors.

In 1990, the new ST-6 transmitters had a software problem resulting in drift of the internal clock by two hours in a six week period for PTTs #823 and #839 (Figures 11 and 12). This drift resulted in fewer successful uplinks during the fourth transmission period (noon to dusk). Figure 13 illustrates the total number of orbits (passes) for each period and each PTT while Figure 14 illustrates the number of transmissions per period.

The number of transmissions per minute and their relationship to periods of the day are shown in Figures 15 and 16. PTTs with the largest sample size (N = 126 for PTT #823 in Figure 15; N = 119 for PTT #839 in Figure 16) show a similar overall average rate of transmission but have different patterns in their relative distribution between periods. Because the transmitters had a minimum transmission rate of 40 to 52 seconds, the maximum number of transmissions per minute was 1.5 to 1.1, respectively.

We expected the number of transmissions/period to reflect the same pattern as the number of passes per period, but Period 1 (dusk to midnight) had the lowest number of transmissions despite having the highest number of passes. This may have been due to less surface resting. The high number of transmissions per minute reported during Periods 2 and 4 for PTT #840 (Figure 16) indicate that the animal was at the surface for long periods, which was confirmed by the discrete dive data (see "Surface Resting"). Thus, animal behavior can affect the number of transmissions received, the probability of locations and location accuracy.

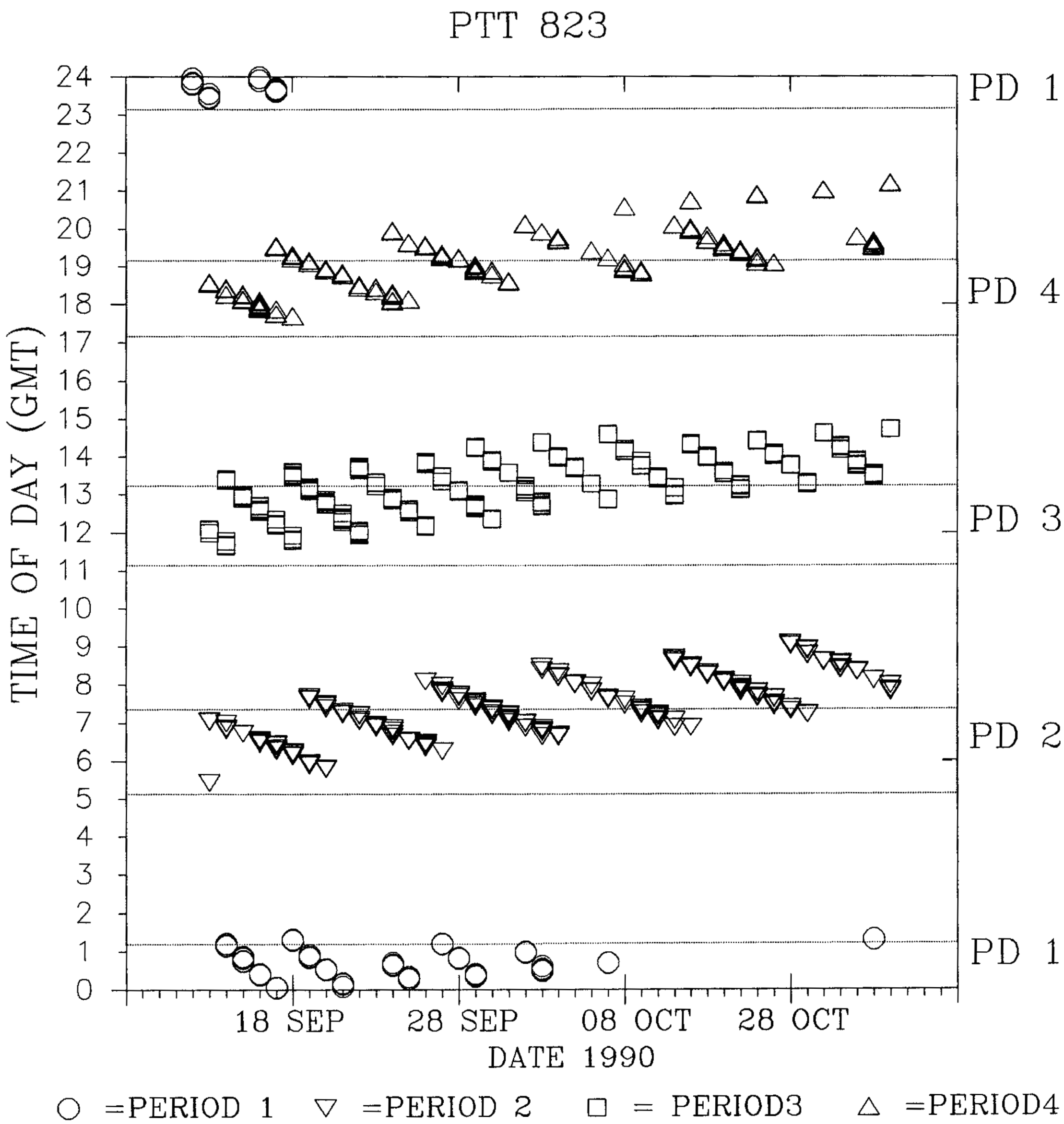


Figure 11. Time and date of transmissions received for PTT #823. Periods (PD 1-4) designate initial 2-hour transmission times.

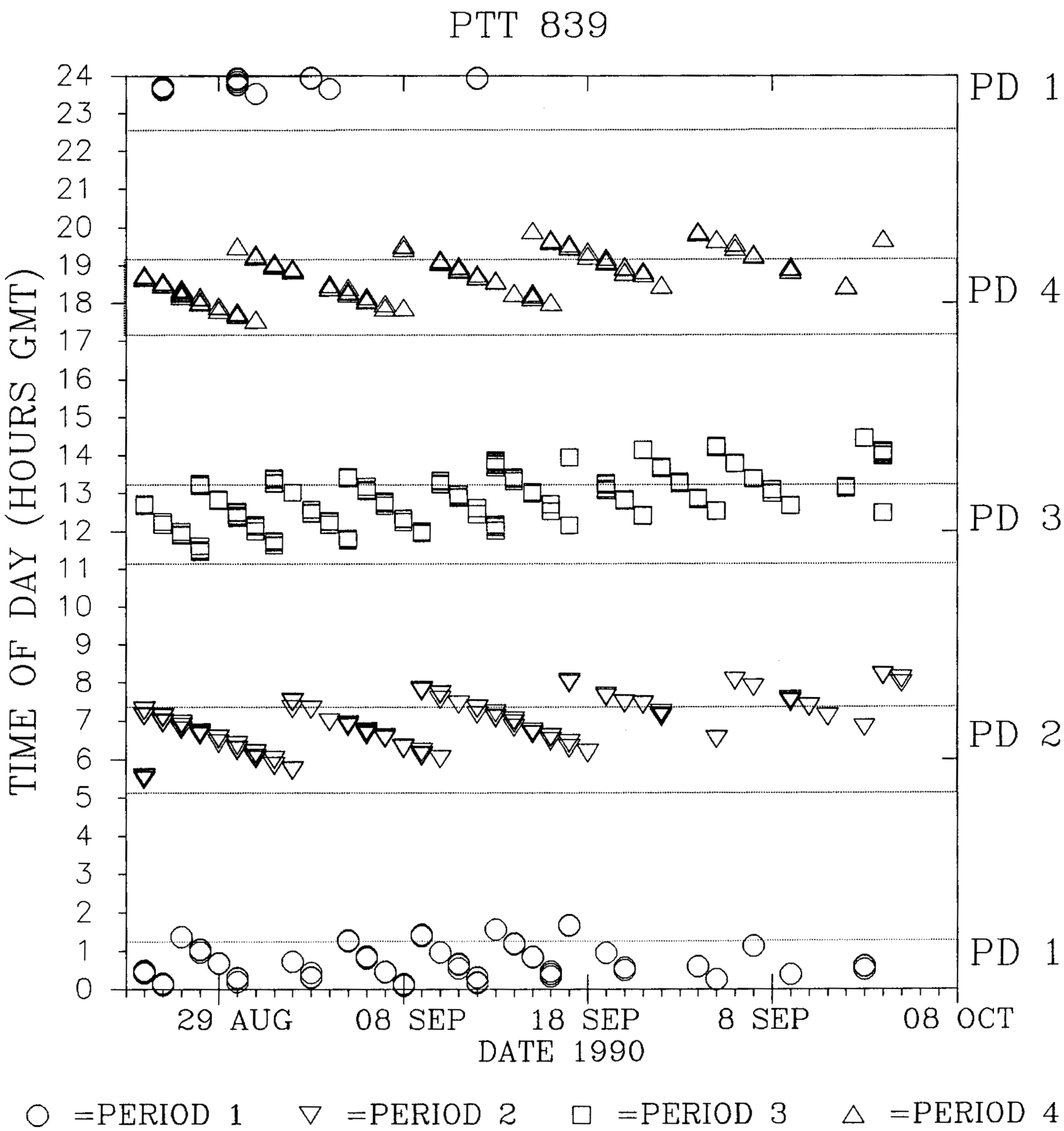


Figure 12. Time and date transmissions were received for PTT #839. Periods (PD 1-4) designate initial 2-hour transmission times.

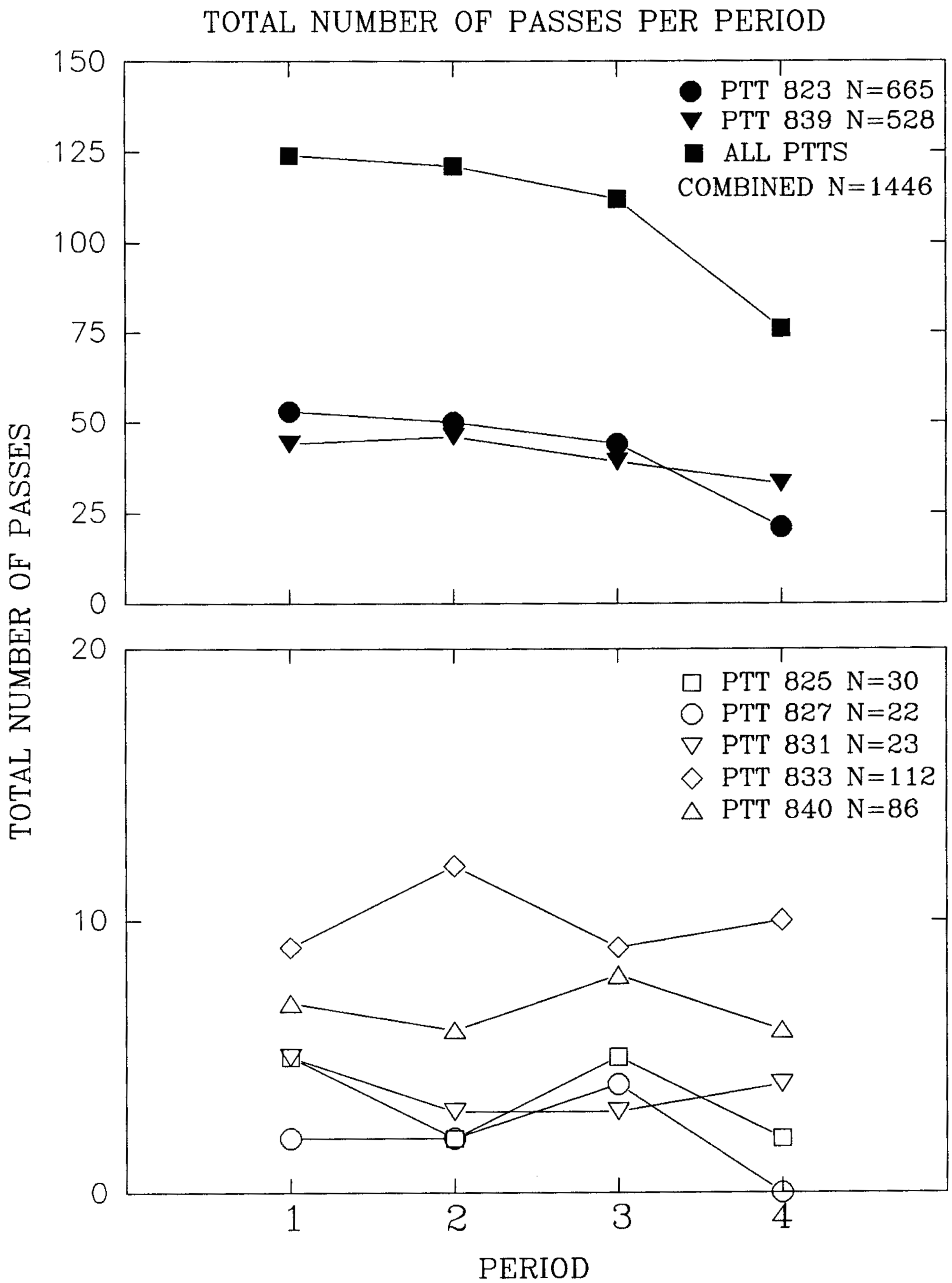


Figure 13. A comparison of the total number of passes received during 6-hour summary periods for PTTs #823, #825, #827, #831, #833, #839 and #840.

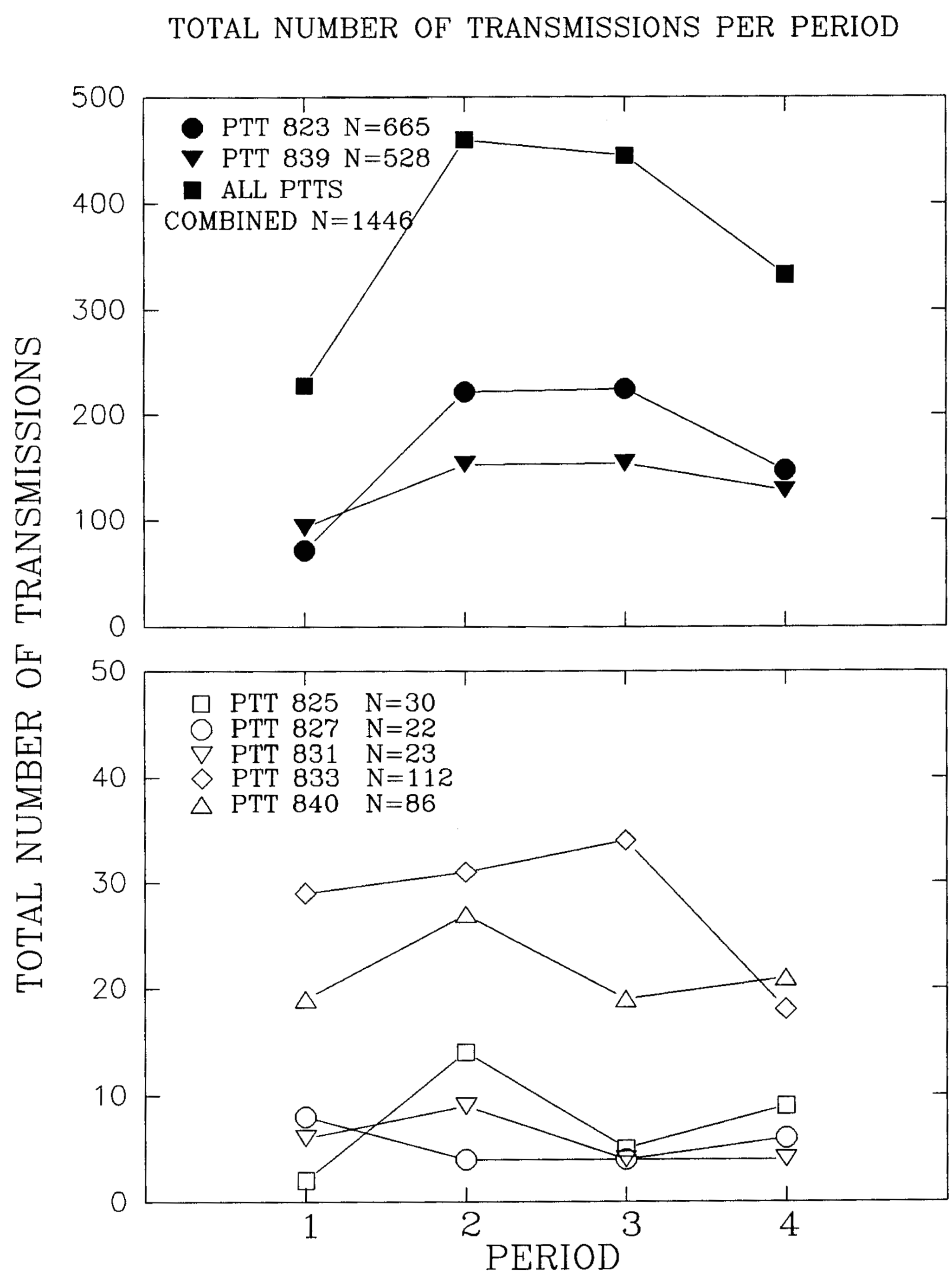


Figure 14. A comparison of the total number of transmissions received during 6-hour summary periods for PTTs #823, #825, #827, #831, #833, #839 and #840.

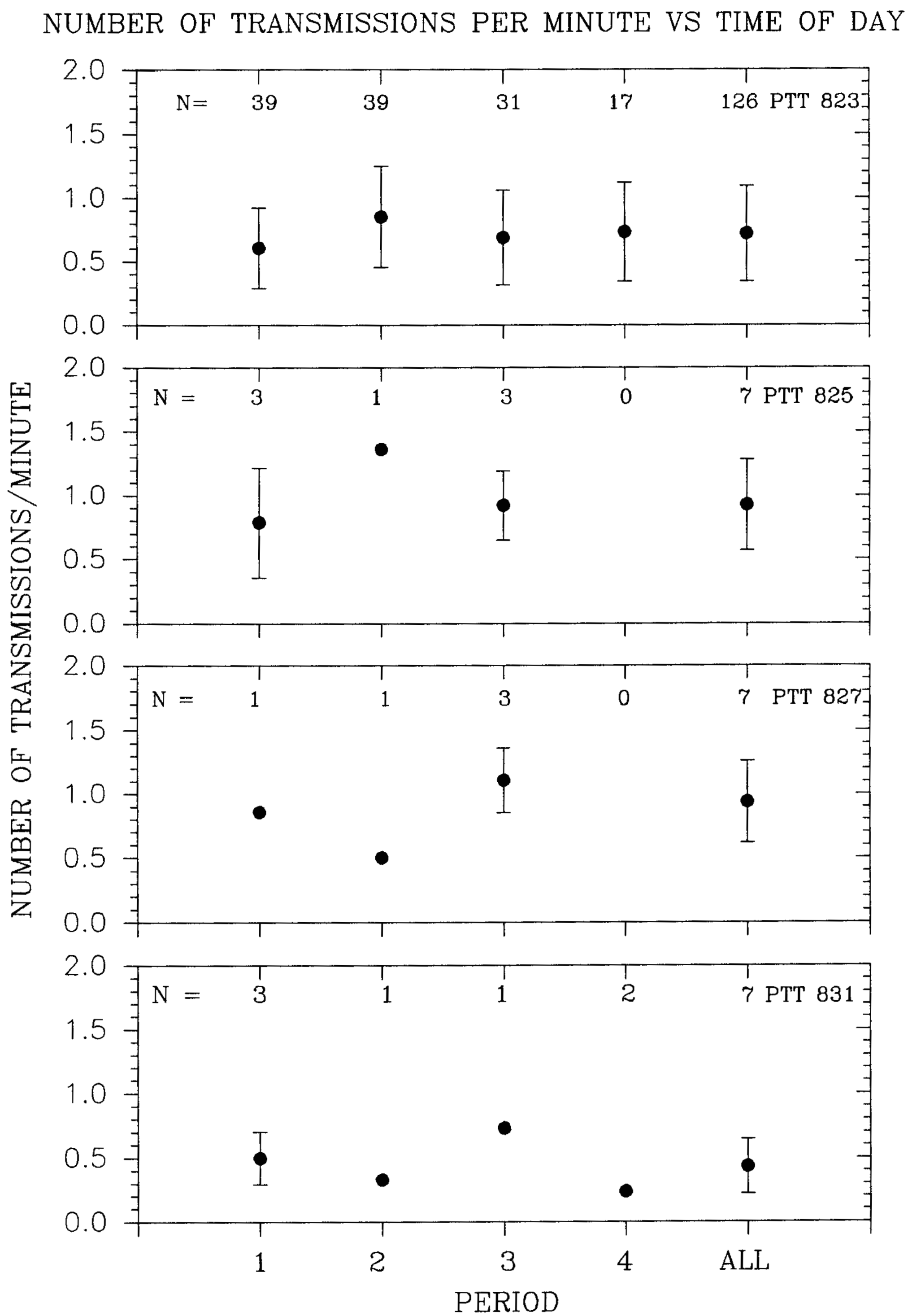


Figure 15. A comparison of the average number of transmissions per minute for each 6-hour summary period for PTTs #823, #825, #827 and #831. Error bars indicate one standard deviation.

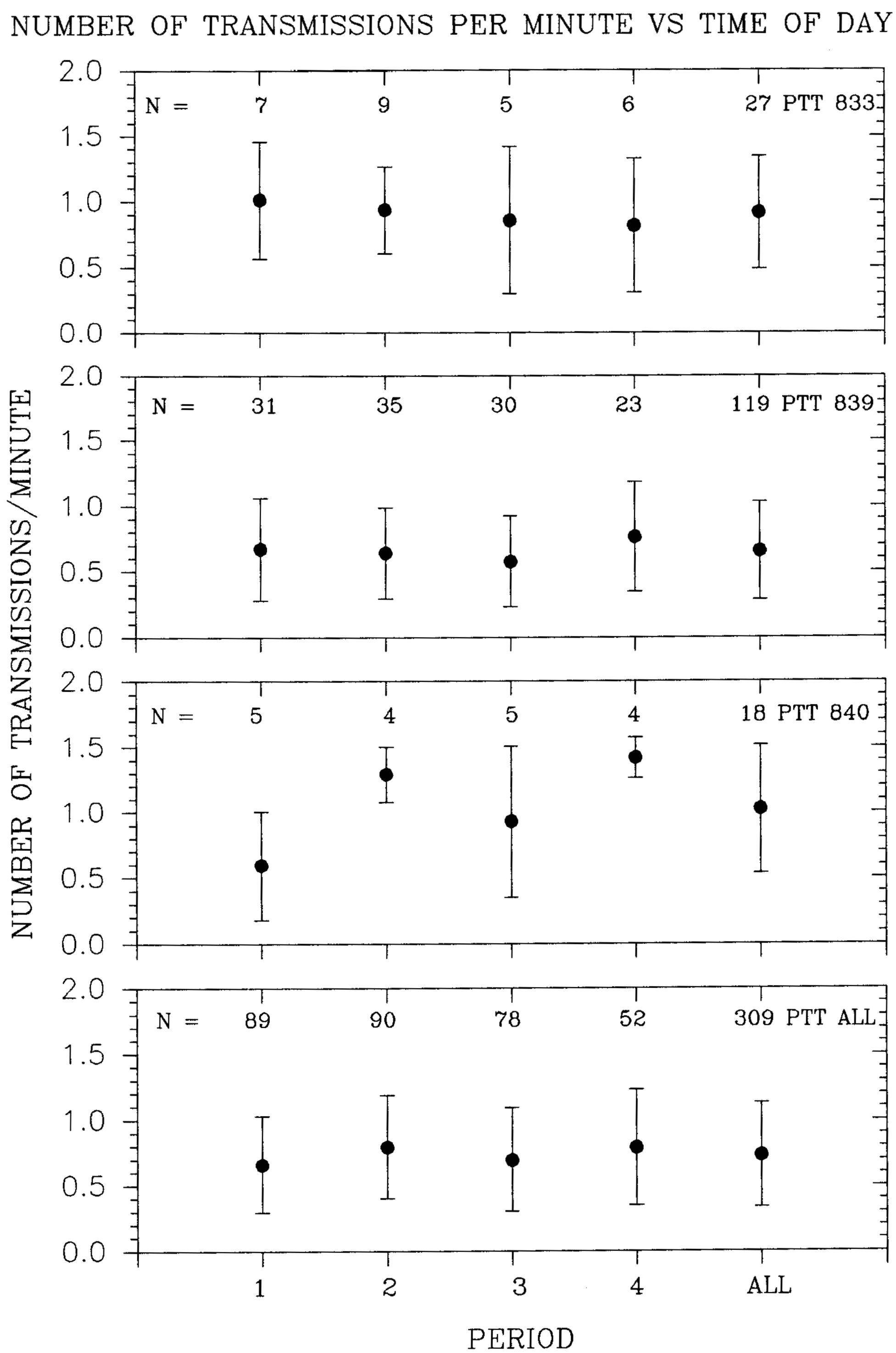


Figure 16. A comparison of the average number of transmissions per minute for each 6-hour summary period for PTTs #833, #839, #840 and all PTTs combined. Error bars indicate one standard deviation.

Locations and Movements

In 1989, 71 locations were determined in 22 days for the only whale (PTT #843, NEA #1146) successfully tracked. Seven of the nine transmitters applied in 1990 provided more than one day of information, but two of these (PTT #827 and PTT #831) did not provide any locations. An insufficient number of messages was obtained from PTT #827 to calculate locations. Service Argos failed to establish a frequency stability file for PTT #831, resulting in a complete loss of location information. (However, sensor data for these animals were available and are included in the analyses.)

During the 1989 and 1990 seasons, 356 locations were computed (an average of 2.3/day) for the six whales. Together they traveled at least 9,590 km. The number of locations varied from 7 - 136 per individual animal and distances traveled varied from 302 - 3,833 km per individual (Table 3). The distances we calculated were based on straight lines between locations and are thus clearly minimum estimates of actual distances traveled.

In 1989, Argos did not classify locations or provide zero class locations. Table 5 identifies the number of locations in each location class for each of the five transmitters deployed during the 1990 season. The lowest location class has an unknown accuracy and accounted for 65% of all locations. Argos claims that 67% of the locations in each class are actually within the specified distance associated with that class. Thus, 67% of the locations in Class 1 are within 1 km from their calculated position. The low number of transmissions during Period 1 dramatically affected the number of locations during that period.

LOCATION CLASS INFORMATION

LOCATION CLASS	ALL PTTS (%)	PTT 823 (%)	PTT 825 (%)	PTT 833 (%)	PTT 839 (%)	PTT 840 (%)	LOCATION ACCURACY*
0	197 (68%)	85 (63%)	5 (83%)	22 (88%)	73 (66%)	12 (86%)	UNKNOWN
1	59 (20%)	31 (23%)	1 (17%)	2 (8%)	23 (21%)	2 (14%)	± 1 KM
2	32 (11%)	17 (13%)	0 (0%)	1 (4%)	14 (13%)	0 (0%)	± 350 M
3	2 (1%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	± 150 M
TOTAL	290	135	6	25	110	14	

Table 5. Summary of location classes for PTTs #823, #825, #833, #839 and #840.

Juveniles

Two juveniles were tagged (PTT #827 and PTT #833) and data were received for 3 and 12 days respectively. Of the two, only PTT #833 (NEA #1981), an animal of unknown sex, provided locations. It stayed in the same general area, traveling at least 576 km between 26 locations (Figure 17) for an average of 48 km/day. The majority of this juvenile's activity was at the northern end of the deepest part of the main Fundy shipping channel, along the 180 m (100 fathom) contour line (Figure 18). This general region was where most whales were tagged because it had the highest concentration of right whales. It is also the main shipping channel in the Bay of Fundy (see "Conclusions").

Females with calves

Two adult females with calves were tagged. One of these, "Wart" (PTT #839, NEA #1140), was tracked for 42 days and traveled at least 3,833 km between 111 locations for an average of 2.6 locations and 90 km per day (Figure 19). The first two weeks after tagging were spent in the Fundy (shipping) Channel east of Grand Manan and the shallower waters south of Grand Manan. During the next three weeks, the animal traveled a largely coastal route (usually within 120 km of shore) to New Jersey and subsequently returned to the Bay of Fundy. This movement demonstrated four major points:

1) right whales can move long distances over short periods of time;

2) the resighting of the tagged animal six weeks later in the same area would previously have been misinterpreted as a minimum estimate of residency time in the Bay of Fundy, which it was not;

3) some animals prefer a "nearshore" route of movement; and

4) females with calves have sufficient energy reserves to travel widely and are not restricted to a specific area during this time of year.

It is not known why this pair traveled so far or took this route. Among the many possibilities are: searching for food, introducing the calf to areas of potential feeding importance, exercising the calf, and recreation.

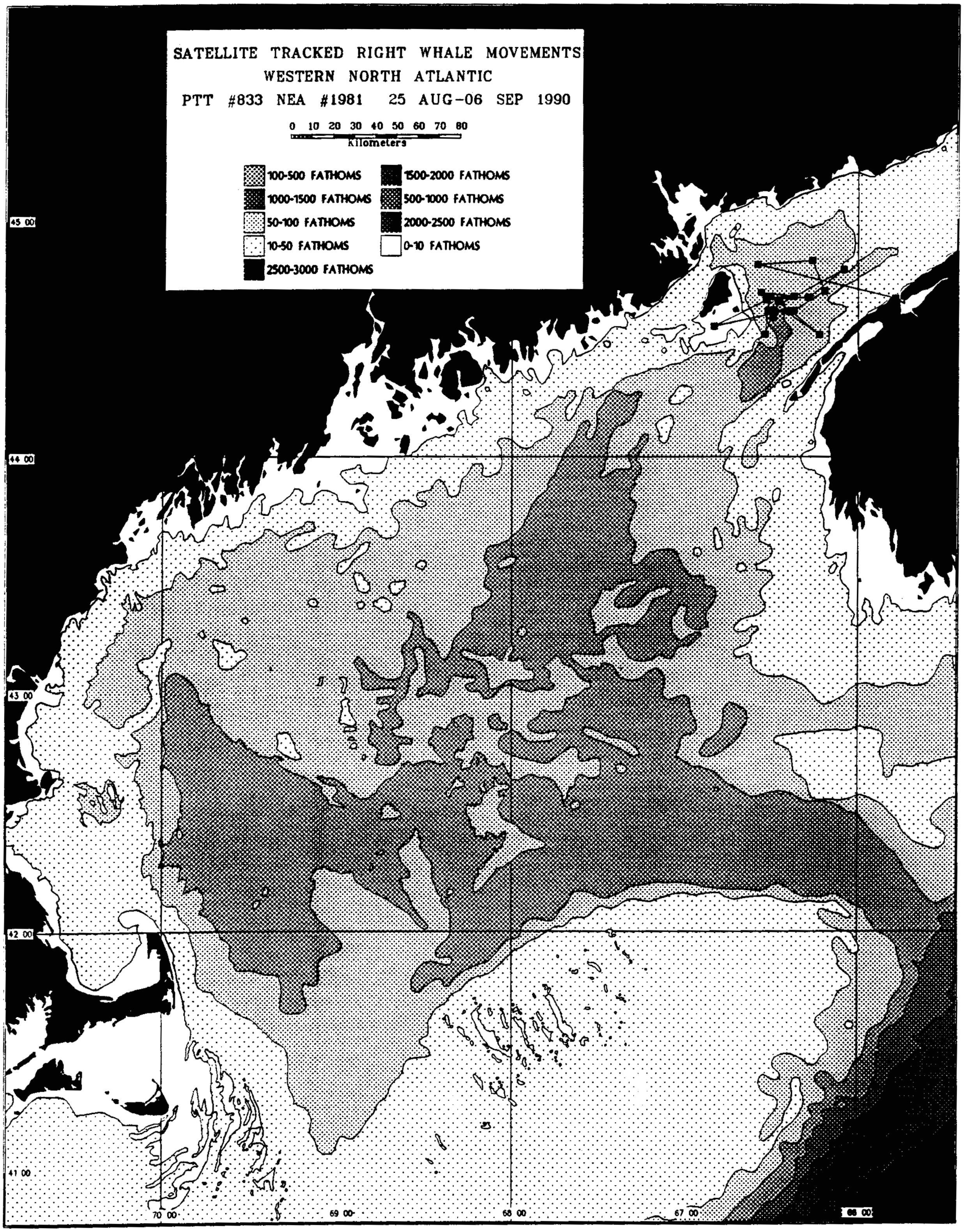


Figure 17. Satellite-monitored movements of PTT #833 (NEA #1981), a juvenile animal of unknown sex. See Figure 18 for more detailed scale. Note: lines show chronological order of locations and a minimum travel of 576 km.

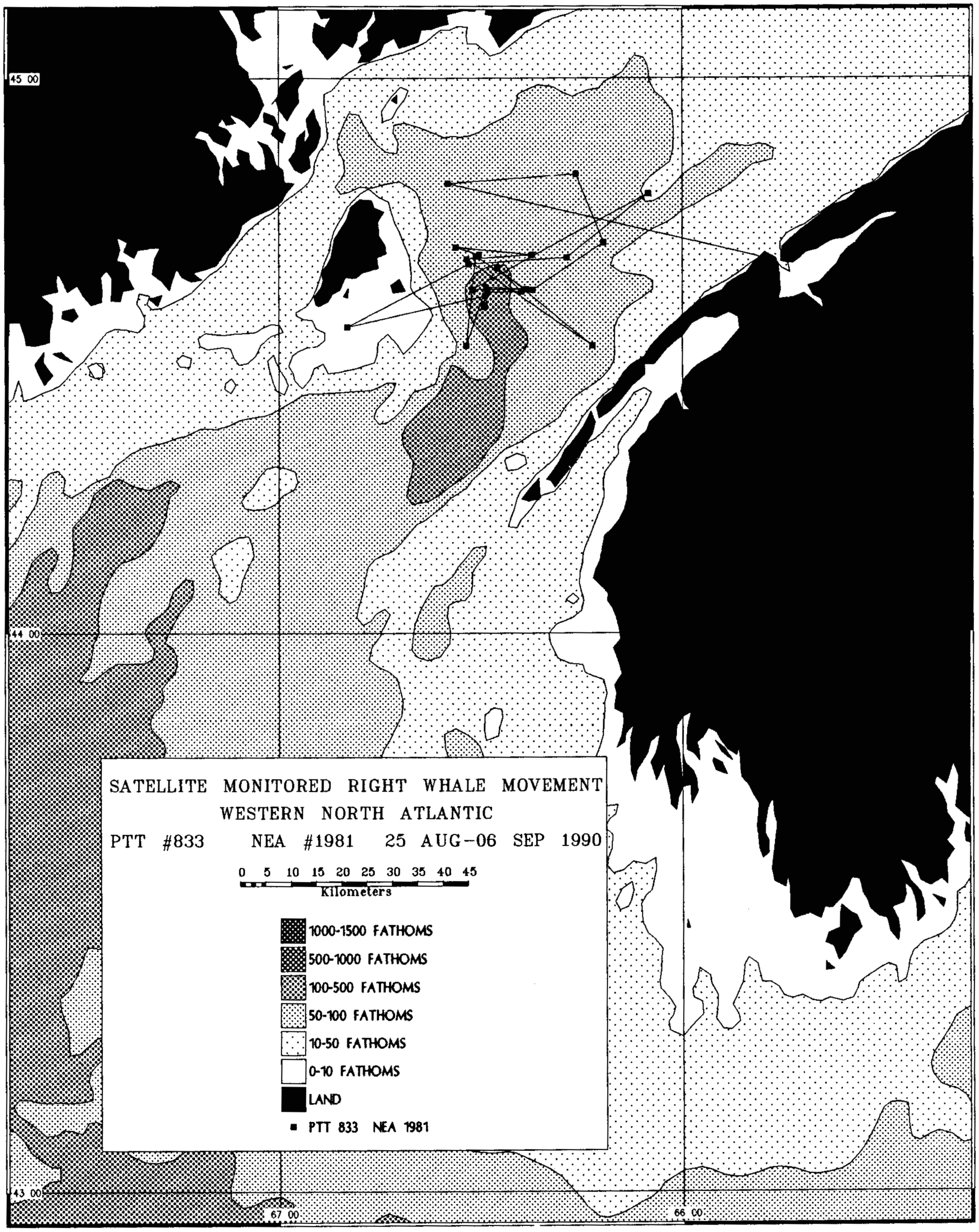


Figure 18. Details of satellite-monitored movements of PTT #833 (NEA #1981), a juvenile animal of unknown sex.

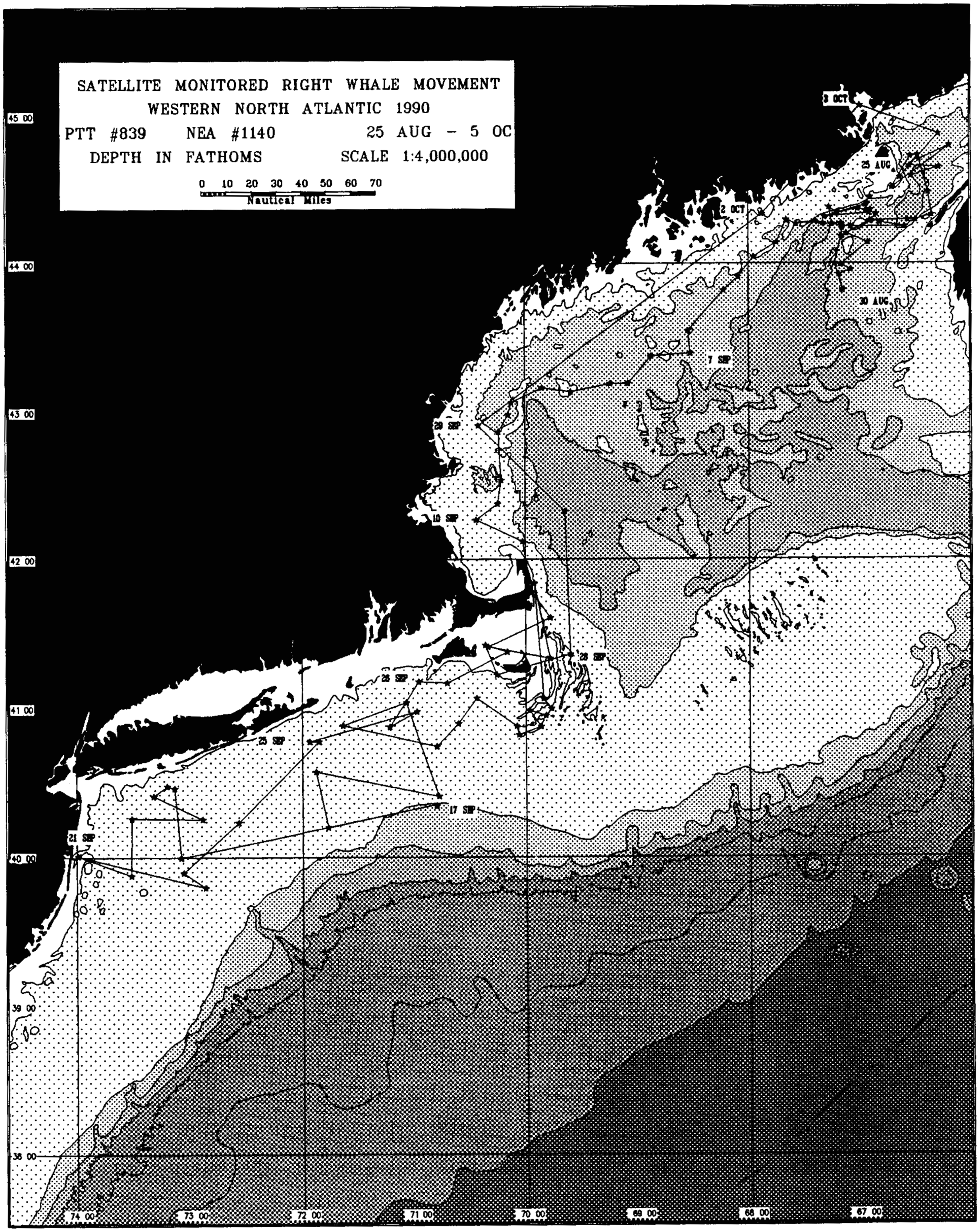


Figure 19. Satellite-monitored movements of PTT #839 (NEA #1140), an adult female with her calf. Note: lines show chronological order of locations and a minimum travel of 3,833 km.

A second female with a calf (PTT #825, NEA #1629), showed a restricted range similar to the juvenile's, moving only 302 km in 10 days between seven locations (Figure 20) for an average of only 30 km/day. The female's nursing posture at the surface may have allowed her to breathe without her transmitter being exposed as frequently as the juvenile's. The average rate of speed for this female/calf pair was 1.25 km/hr. This included travel in the Fundy Channel, an area of heavy ship traffic.

Adult female

One adult female ("Stripe") tagged with PTT #840 (NEA #1135) has a well documented reproductive history (Appendix C) and last had a calf in 1987. On the basis of her previous calving intervals, she was expected to be estrous in the 1990 season and produce a calf in the winter of 1991 - 1992. She was observed in September 1991 with a calf and was, therefore, pregnant in 1990. When first sighted during the 1990 season by the NEA whale research group, she was unusually active, moving around rapidly at the surface, but was never seen in breeding SAGs. Although the tag survived only seven days, it provided 15 locations which documented a minimum of 793 km of travel for an average daily speed of 113 km per day (Figure 21). This was the highest average speed of any animal recorded during the study and encompassed movements from the Bay of Fundy to Brown's Bank, Baccaro Bank and Emerald Basin (all areas known for large surface active breeding aggregations during this time of year). These movements might be expected of an estrous female seeking out areas of high male concentration, but was a bit surprising for a pregnant female, and may suggest that these areas are also important for feeding.

Adult males

Three adult males were tagged. An adult male (PTT #843, NEA #1140), known as "Van Halen" was tagged on 15 October 1989 (Figure 22). This was the last of the "decent" weather in 1989 and the latest in the year that any whale was tagged. It was also the first whale successfully tagged in this project. "Van Halen" moved south to Brown's Bank, east to Baccaro Bank and then traversed the Gulf of Maine to Jeffrey's Ledge in the western Gulf. In 22 days, this animal covered 1523 km ($\bar{x}$ = 69 km/day). The first week of movements mirrored those of the adult female "Stripe" (PTT #840) and suggested a male in search of breeding aggregations. However, in the western Gulf of Maine, "Van Halen" stopped moving at high speed and changed his diving characteristics. Activity was concentrated in two areas with productive physical features: the eastern edge of Jeffrey's Ledge (Figure 23), known for upwelling, and north of Jeffrey's Ledge where a seasonal eddy could favor copepod concentration (Bigelow, 1927).

Another adult male, (PTT #823, NEA #1421) was tagged 12 September 1990 and traveled at an average rate of 70 km/day covering at least 3,030 km in 43 days between 136 locations (Figure 24). "Willie" immediately moved south out of the Bay of Fundy and then traveled southeast to an area 500 km offshore, where 2,200 m deep sea mounts rise from a depth of 4,200 m. The whale then went north through Baccaro Banks, Emerald Basin and Roseway Basin and then south through the same area. Right whales are commonly seen in

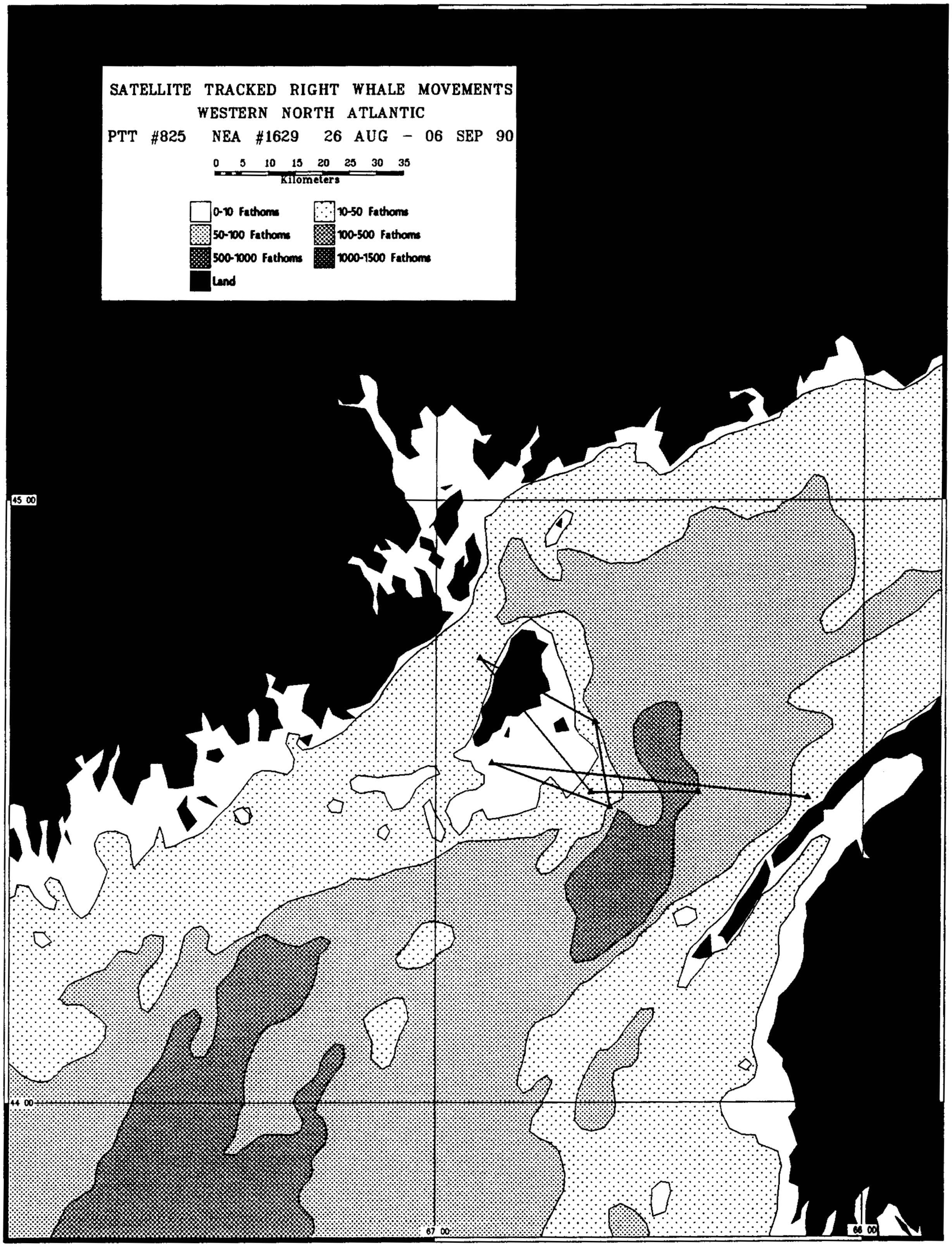


Figure 20. Satellite-monitored movements of PTT #825 (NEA #1629), an adult female with a calf. Note: lines show chronological order of locations and a minimum travel of 302 km.

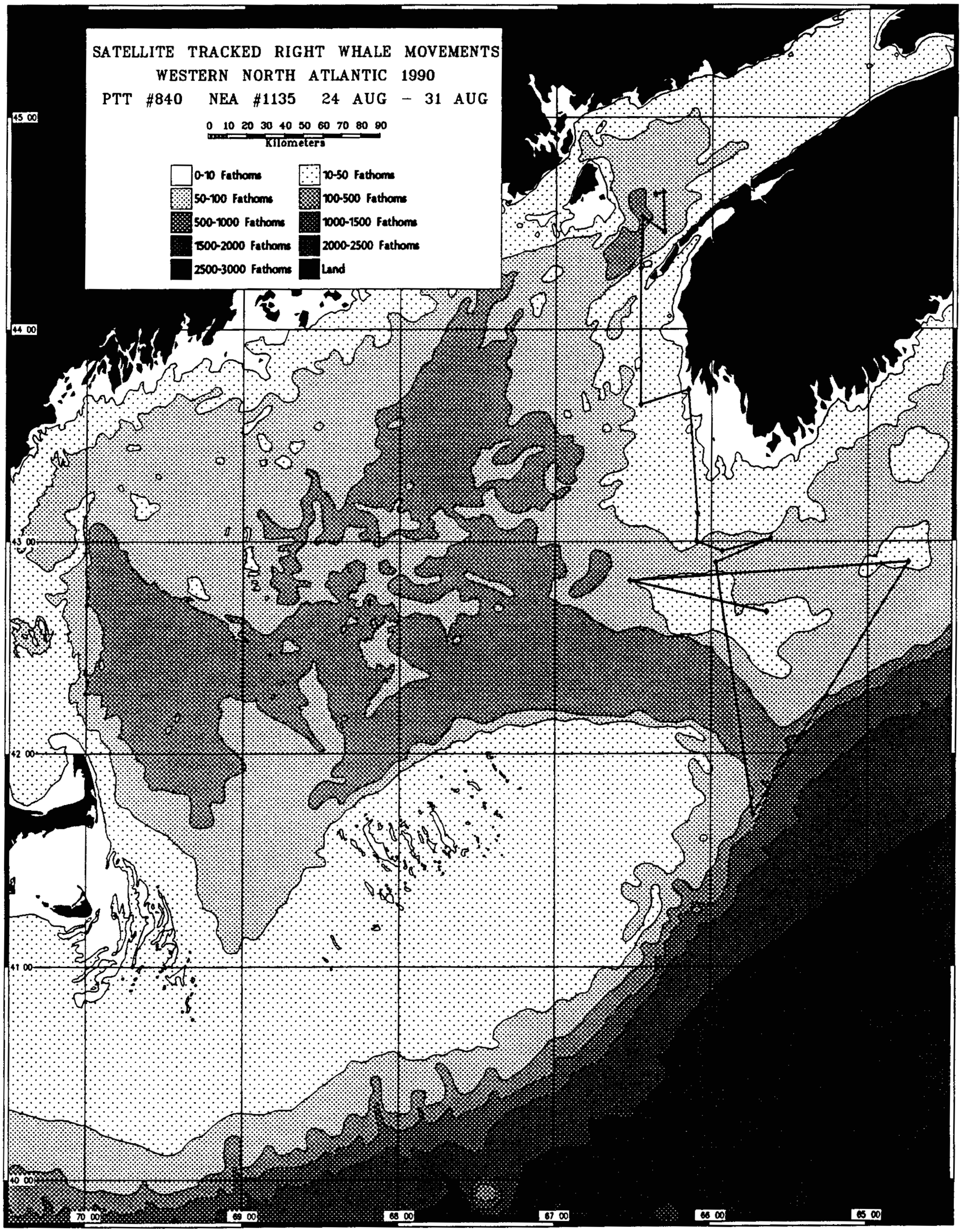


Figure 21. Satellite-monitored movements of PTT #840 (NEA #1135), a pregnant, adult female. Note: lines show chronological order of locations and a minimum travel of 793 km.

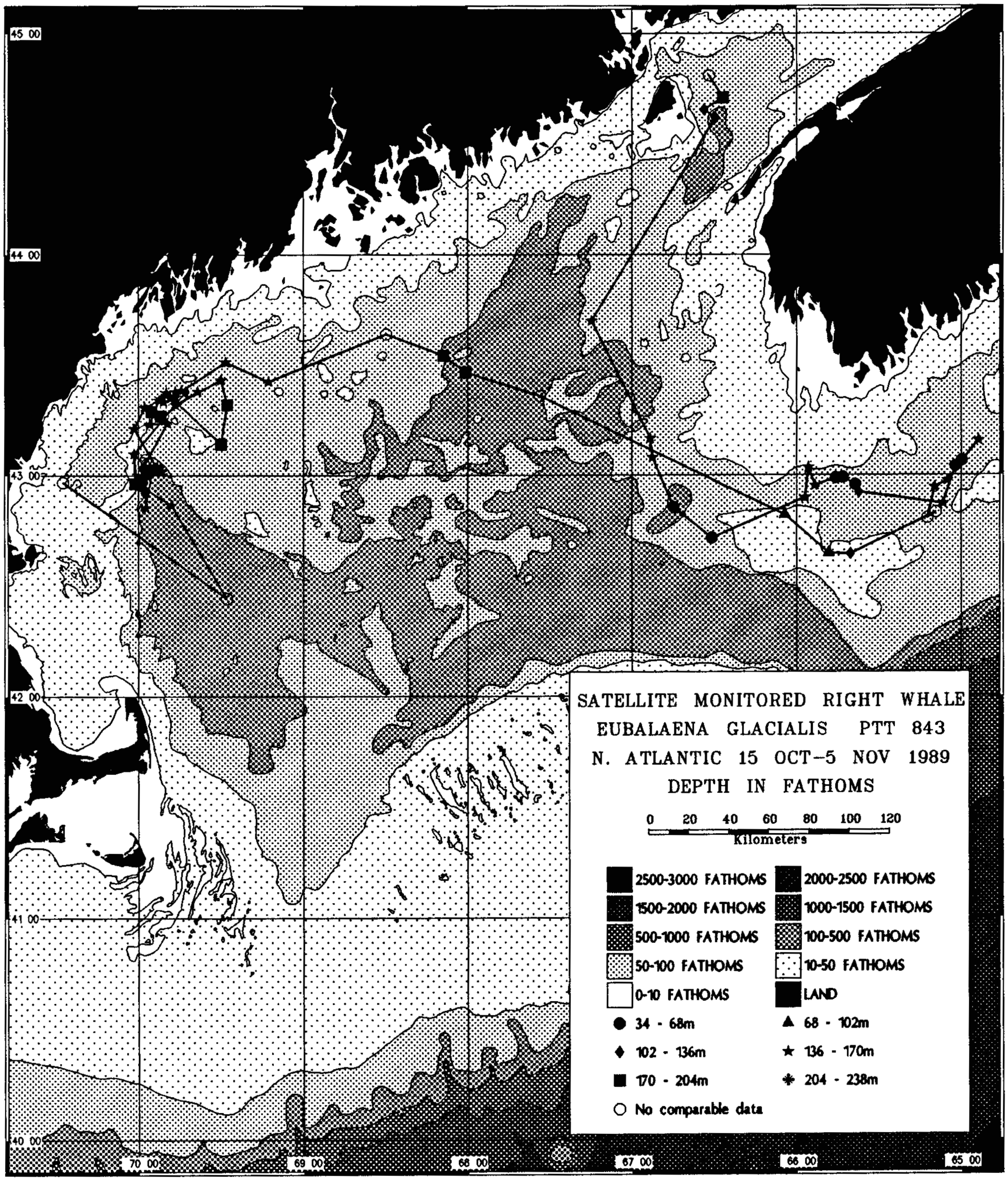


Figure 22. Satellite-monitored movements of PTT #843 (NEA #1146), an adult male tagged in 1989. Note: lines show chronological order of locations and a minimum travel of 1,523 km. Symbols represent the deepest dive during the 4-hour summary period when location was obtained.

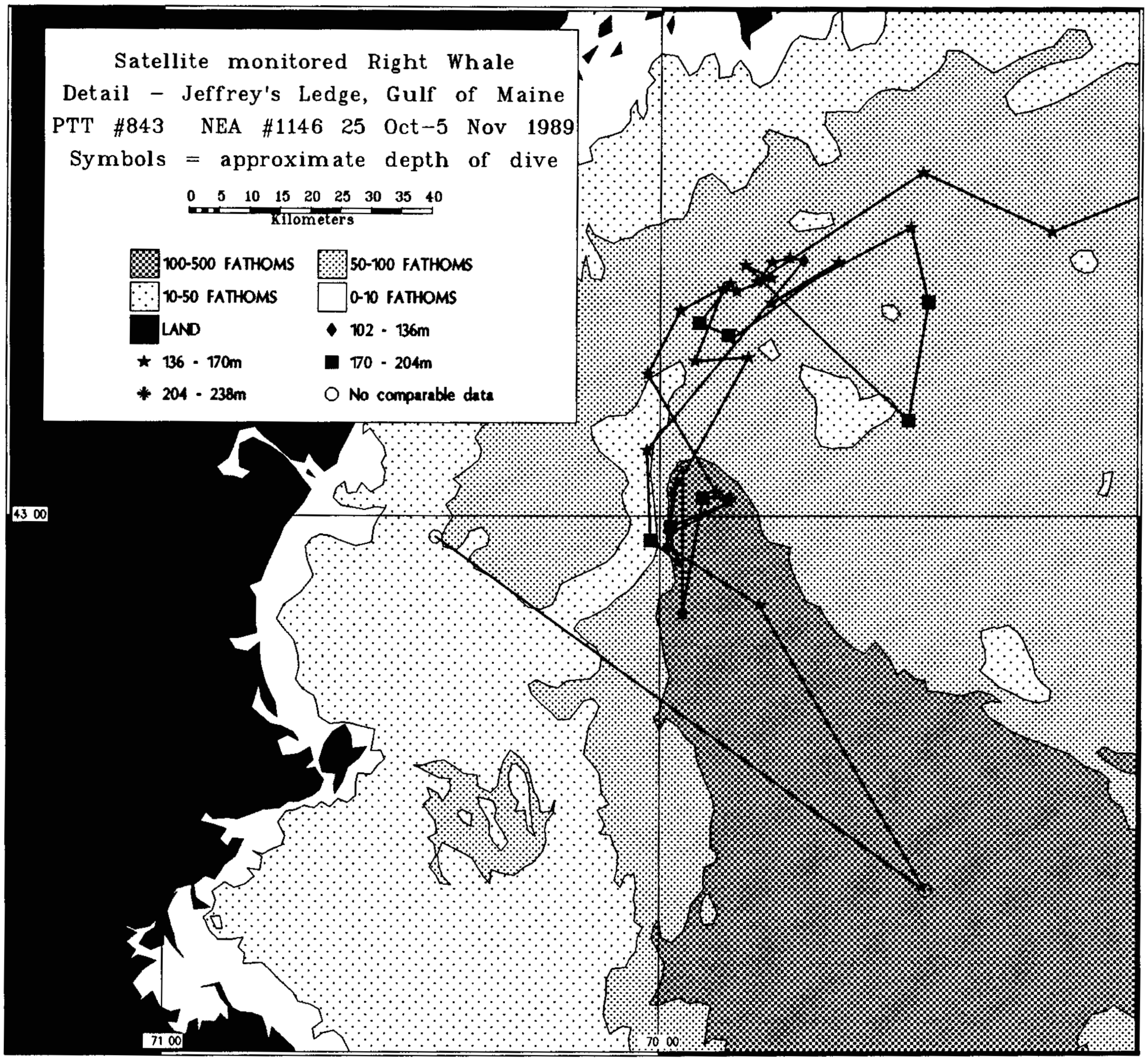


Figure 23. Satellite-monitored movements of PTT #843 (NEA #1146), an adult male. Detail of Jeffrey's Ledge, Gulf of Maine. Symbols represent the deepest dive during the 4-hour summary period when location was obtained.

these areas in late summer. The last two days were spent over German Bank and Lurcher Shoal off the southern tip of Nova Scotia (see Figure 24). Further interpretation of these movements is in the discussion of satellite imagery and sea surface temperatures. A third adult male, "Necklace" (PTT #831, NEA #1152), provided dive data for 15 days but due to an Argos software problem, never produced any location information.

Animals were usually relocated by the observation vessel using Argos-acquired locations despite a two to six hour delay in obtaining these locations. Observation was most common for three whales (four times for PTT #833, and three times for #839 and #825, see Table 2). PTT #833 and #825 were observed by us and stayed in a small area near the tagging site. Several animals departed the area soon after tagging, and it was impossible to confirm their locations outside our study area with the available logistics. "Wart," a female with a calf, was opportunistically resighted three times by other whale researchers working in the Gulf of Maine/BOF. All reported that the calf was still with the female (C. Mayo, pers. comm., D. Wiley, pers. comm., and C. Hancock, pers. comm.). Argos locations were fortuitously determined at the same time and were within 1 km of the LORAN-determined locations reported by these researchers.

Water Depths

Five of six whales spent all of their time in water less than 500 fathoms deep. All six spent the majority of their time in water less than 200 fathoms. Water depths were taken from NOAA charts 13009, 13003, 1109 (US) and Canadian Department of Fisheries and Oceans #L/C 4003 and L/C 4011. A summary of the water depth preferences for individuals is found in Table 6. (These charts reported water depths in fathoms and for convenience we refer to water depths in fathoms in this section only. Table 6 also shows these values in meters.) Because of their long range movements, more emphasis is given to: 1) "Stripe," the pregnant female (PTT #840); 2) "Wart," the female with a calf (PTT #839); 3) "Willie," an adult male (PTT #823); and 4) another adult male, "Van Halen," (PTT #843).

All of "Stripe's" recorded movements (Figure 21) were within the 500 fathom contour. Only 6.7% of the activity was in less than 10 fathoms of water while the greatest activity was in the 10 - 50 fathom range (40%) or 50 - 100 fathoms (40%). Only 13.3% of the activity was in water deeper than 100 fathoms.

"Wart's" movements (Figure 19) were quite comparable with 9% of movement in less than 10 fathoms, 44% in the 10 - 50 fathom range, 43% in the 50 - 100 fathom range and only 4% in depths greater than 100 fathoms.

"Willie" (PTT #823) spent 37% of his time in water deeper than 100 fathoms (Figure 24). Less than 1% of "Willie's" time was in water less than 18 fathoms. The first two categories of highest rank were 37% in 10 - 50 fathom water and 25% in 50 - 100 fathoms including 13% in water 2500 - 3000 fathoms. We believe "Van Halen's" (PTT #843) track (Figure 22) can be examined as two separate activities: high speed movements and feeding.

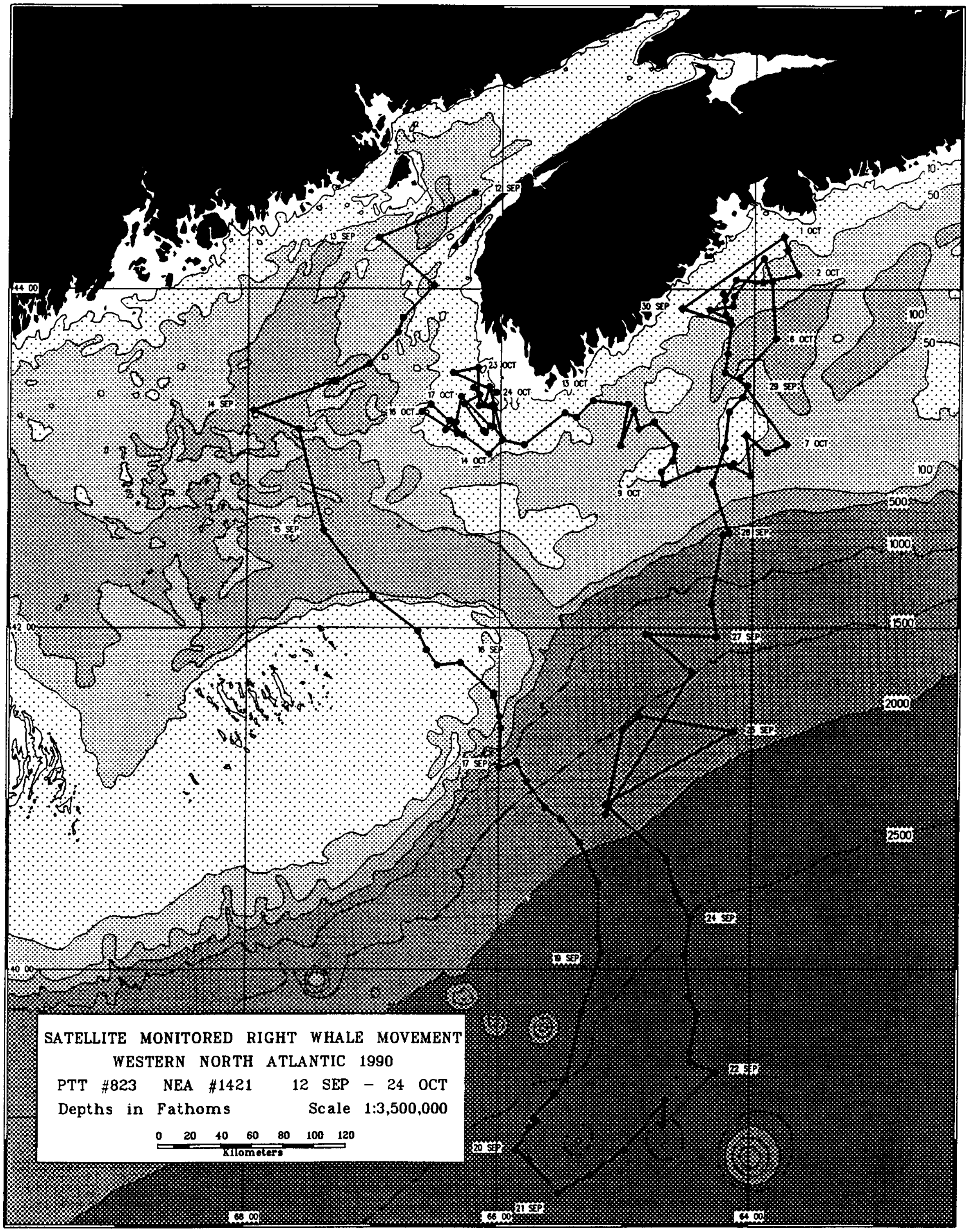


Figure 24. Satellite-monitored movements of PTT #823 (NEA #1421), an adult male. Note: lines show chronological order of locations and a minimum travel of 3,030 km.

		PTT #823		PTT #825		PTT #833		PTT #839		PTT #840		PTT #843	
DEPTH (Fathoms)	DEPTH (Meters)	N	%	N	%	N	%	N	%	N	%	N	%
0-10	0- 18	1	.74	1	14.29	2	8.00	10	9.17	1	6.67	0	0
10-50	18- 91	50	36.76	4	57.14	1	4.00	48	44.04	6	40.00	12	8.33
50-100	91- 182	34	25.00	2	28.57	15	60.00	47	43.12	6	40.00	98	68.06
100-500	182- 914	8	5.88	0	0	7	28.00	4	3.67	2	13.33	34	23.61
500-1000	914-1829	2	1.47	0	0	0	0	0	0	0	0	0	0
1000-1500	1829-2743	7	5.15	0	0	0	0	0	0	0	0	0	0
1500-2000	2743-3657	8	5.88	0	0	0	0	0	0	0	0	0	0
2000-2500	3657-4572	8	5.88	0	0	0	0	0	0	0	0	0	0
2500-3000	4572-5486	18	13.24	0	0	0	0	0	0	0	0	0	0

Table 6. Frequencies of locations in various depths of water for PTTs #823, #825, #833, #839, #840 and #843.

The high speed movements are similar to those of "Stripe" (PTT #840) emphasizing 50 - 100 fathom depths. Overall only 8% of PTT #843's dives were in less than 50 fathoms; 68% were in 50 - 100 fathoms; and 24% were in the 100 - 500 fathom category. Figure 23 demonstrates the preference "Van Halen" (PTT #843) showed for water slightly deeper than the 183 m (100 fathoms) contour which has been noted in the Great South Channel by Winn, et al. (CeTAP 1982).

Dive Depths

In 1989, "Van Halen's" (PTT #843) transmitter was equipped with a pressure sensor to describe dive depths. The deepest dive during the 4-hour summary period was recorded and indicated dives to, or near, the bottom during most of the periods for which there were locations (Figure 25). Thus, it appears that some right whales routinely sample the water column from surface to bottom. As noted previously, right whales are observed in the Bay of Fundy surfacing in water exceeding 200 m with mud on their rostrum (S. Kraus, pers. comm.). Maximum dive depths of 272 - 306 m were recorded for "Van Halen" (PTT #843). A closer examination reveals two areas where dives did not appear to reach the bottom. One area, early in the records, was on the banks where surface breeding activity is often observed. The other, late in the record, was over a 180 m slope east of Jeffrey's Ledge where upwelling is common and the whale may not have needed to go to the bottom to find food. Right whales may have a preference for slope areas like the one east of Jeffrey's Ledge to take advantage of diel migrating copepods coming up from deeper water (Winn, et al., 1986).

Though there is evidence that right whales may routinely dive to the bottom of their habitat, we only have the discrete dive depths reported for one whale in 1989. This showed that most of the dives greater than 2 minutes were less than 68 m (Figure 26). The summary information showed that the deepest dive in a 4-hour period was most commonly 136 - 170 m (Figure 27). The deepest depths recorded for "Van Halen" occurred after sunrise (Period 3) and the shallowest average maximum depths were around sunset. The latter would coincide with the rise of the deep scattering layer when the average maximum depth of dive was 125 m.

Speeds

Using Argos locations, we calculated the linear distance between two points as the distance traveled, when in fact the whales may have traveled a much greater distance. Thus, the calculated distances and speeds reported here are minimal. In addition, location errors were not taken into consideration, and may have greatly affected estimated distances and speeds. A frequency histogram of the traveling speeds for all 1990 tagged whales is shown in Figure 28 and is further separated by periods of the day. Speeds of 2 - 3 km/hr were most common and speeds in excess of 7 km/hr were uncommon. There were more slow swimming speeds (averaging from 0 - 3 km/hr) between midnight and noon (Periods 2 and 3) than between noon and midnight (Periods 1 and 4). High speeds (above 10 km/hr) occurred most commonly between midnight and dawn (Period 2). Figures 29 - 34 depict the frequency histograms for individual and combined periods for "Van Halen" and five of the whales tagged in 1990. PTT #823 (Figure 30) and PTT #839 (Figure 33) have the largest sample sizes and similar distributions of swimming speeds. A mode of 2 - 3 km/hr was most typical of the dawn to noon period (Period 3).

The average speed of the five 1990 individual whales with location information are depicted with standard deviations in Figure 35. The same information is summarized in Table 7 by period and in Table 8 by category.

The average swimming speed for all whales combined was 3.73 km/hr (range 2.26 - 4.85, N = 289). The highest average speed for all whales combined occurred between midnight and dawn (Period 2). This was also the period of highest speed for the two whales with the largest sample sizes (16.82 km/hr for PTT #839 and 16.15 km/hr for PTT #823). The pregnant female, PTT #840 had the highest overall average swimming speed (4.85 km/hr), followed by female PTT #839 and her calf (4.11 km/hr).

To determine if swimming speed was related to weather, we compared the speed patterns of four whales using the same calendar "x" axis (Figure 36). There was no obvious relationship between the traveling speeds of PTT #823 and PTT #839. However, the analysis was subject to the limitations of how the data were collected. Specifically, much greater distances and thus higher speeds may have been achieved by animals than we calculated from the straight line distances between Argos locations. Also, the animals were sufficiently far apart from one another at times that they may have been experiencing very different weather conditions on the same date.

We do not know the motivation behind the movements described here, but we saw differences in how the whales moved, and have provided some possible explanations in the section "Oceanographic Factors." Some whales were reasonably sedentary (e.g. PTT #825, Figure 20). We had examples of whales which moved long distances apparently in a straight line (PTT #823 going south, Figure 24) or in a zigzag pattern suggesting a search (PTT #839 off Long Island, Figure 19). Figures 37 and 38 depict the travel speeds of PTT #823 and PTT #839 along the segments of their track line. Two features of PTT #823 are worthy of note: 1) the reasonably fast and uniform speeds during the few days before reaching the southern extent of travel coincide with a southern current in the area, and 2) the speeds at the southern extreme of travel are slower than might be expected considering that they coincide with a northeasterly current (see "Oceanographic Factors").

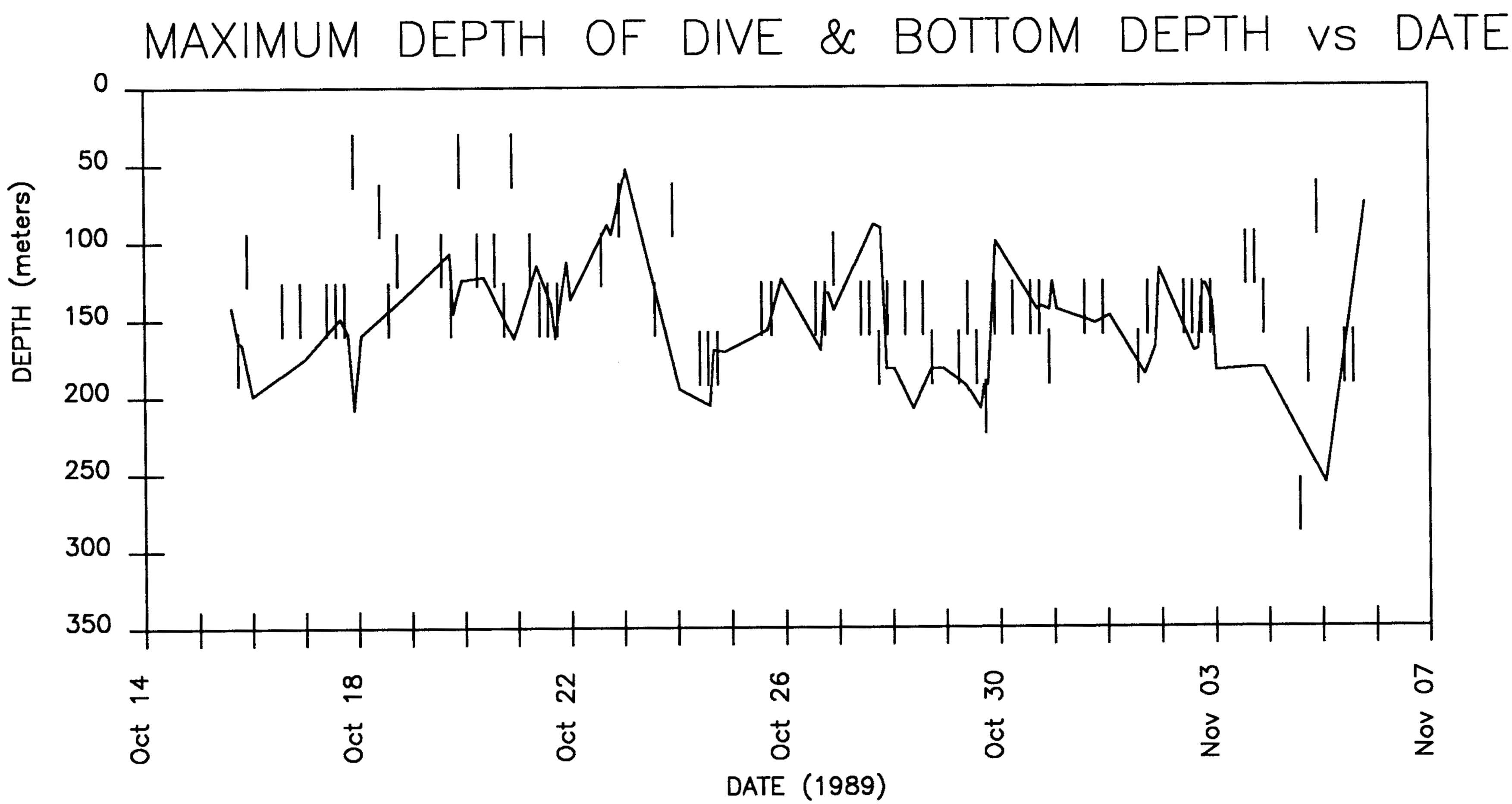


Figure 25. Comparison of depth of dive and water depth at Argos-determined locations for PTT #843 (1989). The continuous line connects sequential estimates of bottom depths at Argos-determined locations but does not infer bottom depths between points. Bottom depths are approximate and were estimated using NOAA chart #13009. Vertical bars represent depth of dive (+/-17 meters) as measured by the PTT.

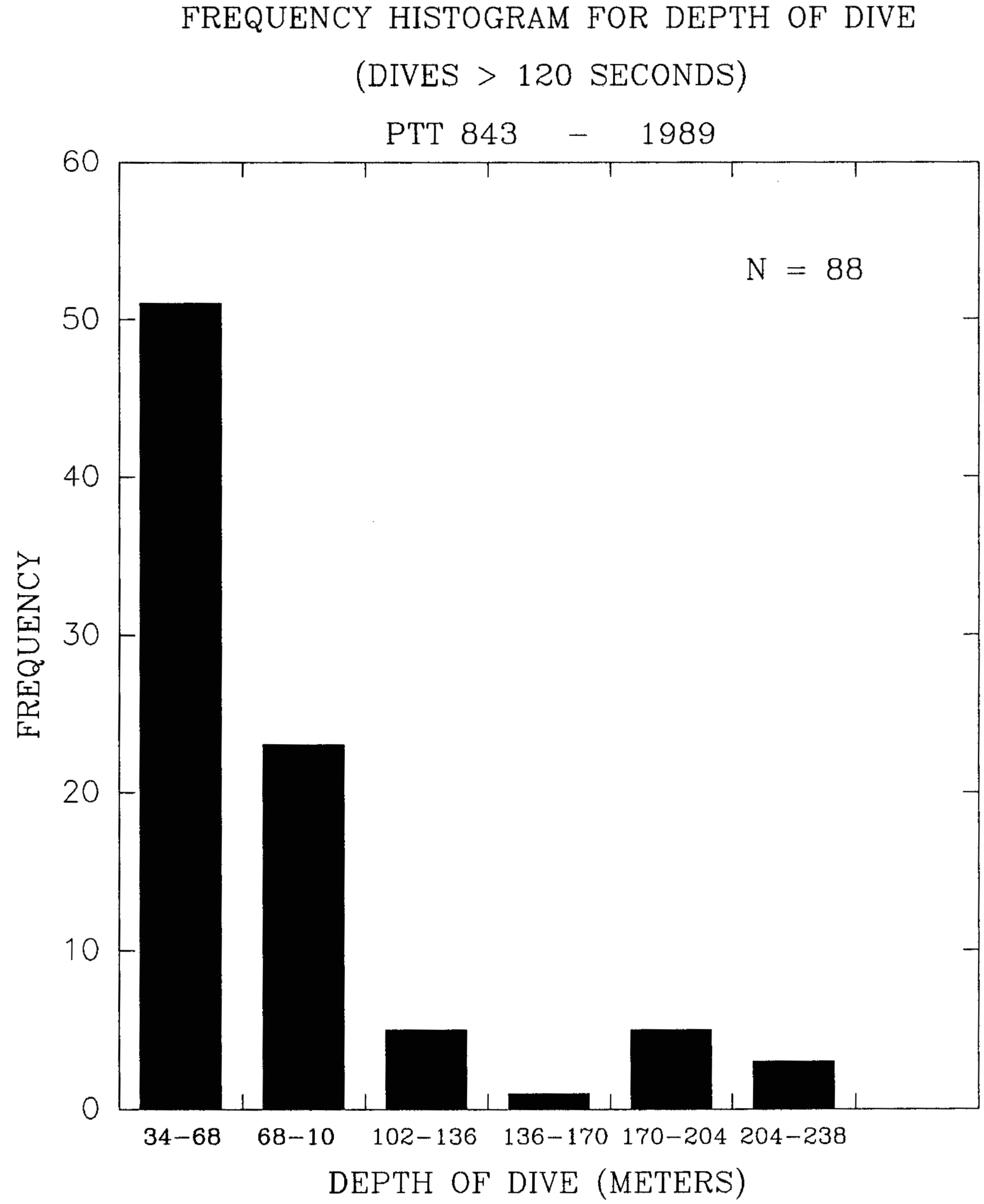


Figure 26. Frequency histogram of discrete dive depths (+/- 17 meters) for PTT #843 (1989).

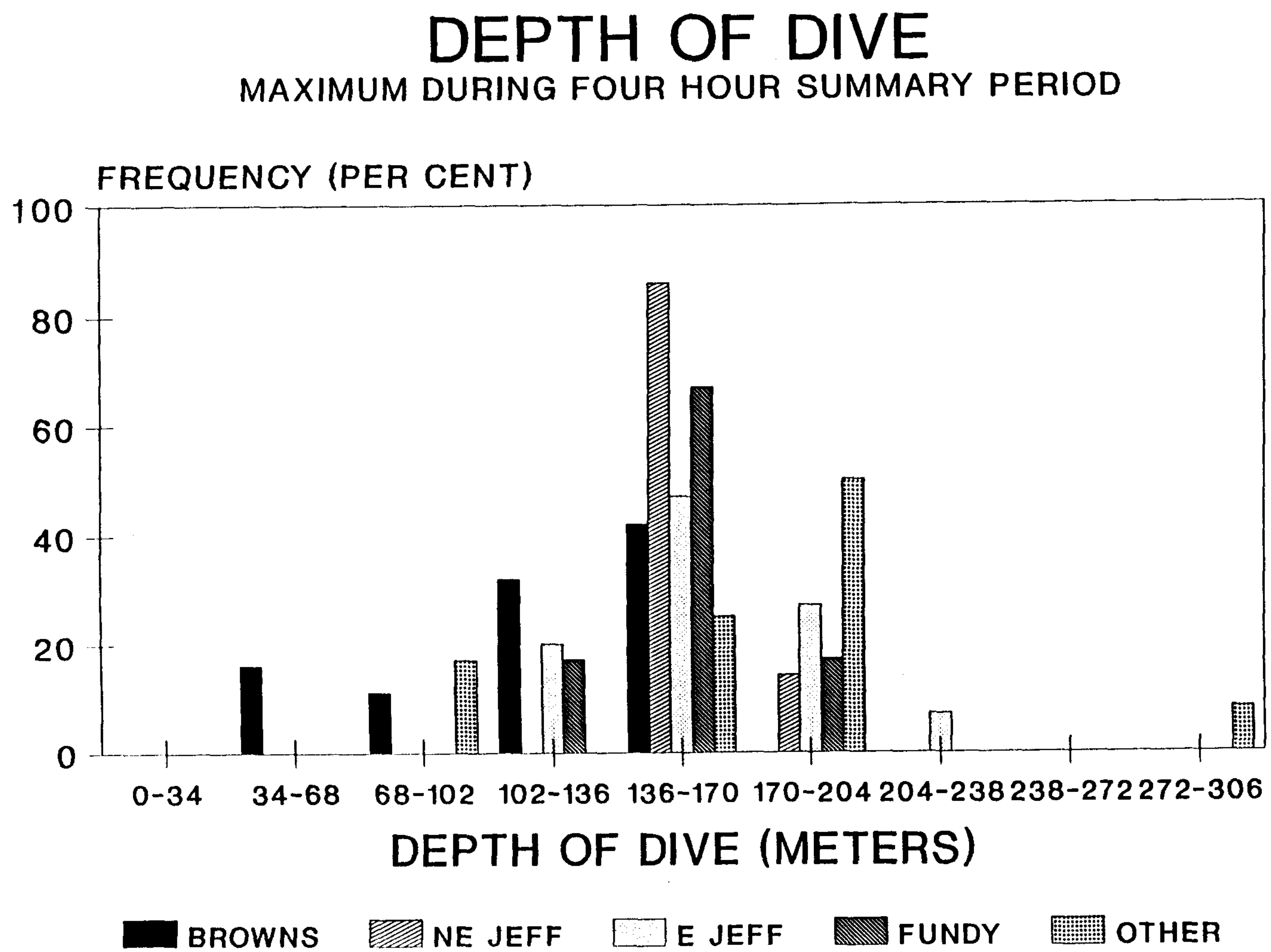


Figure 27. Comparison of 1989 frequency distributions of maximum dive depths (from 4-hour summary periods) by region. Depth resolution is 34 meters.

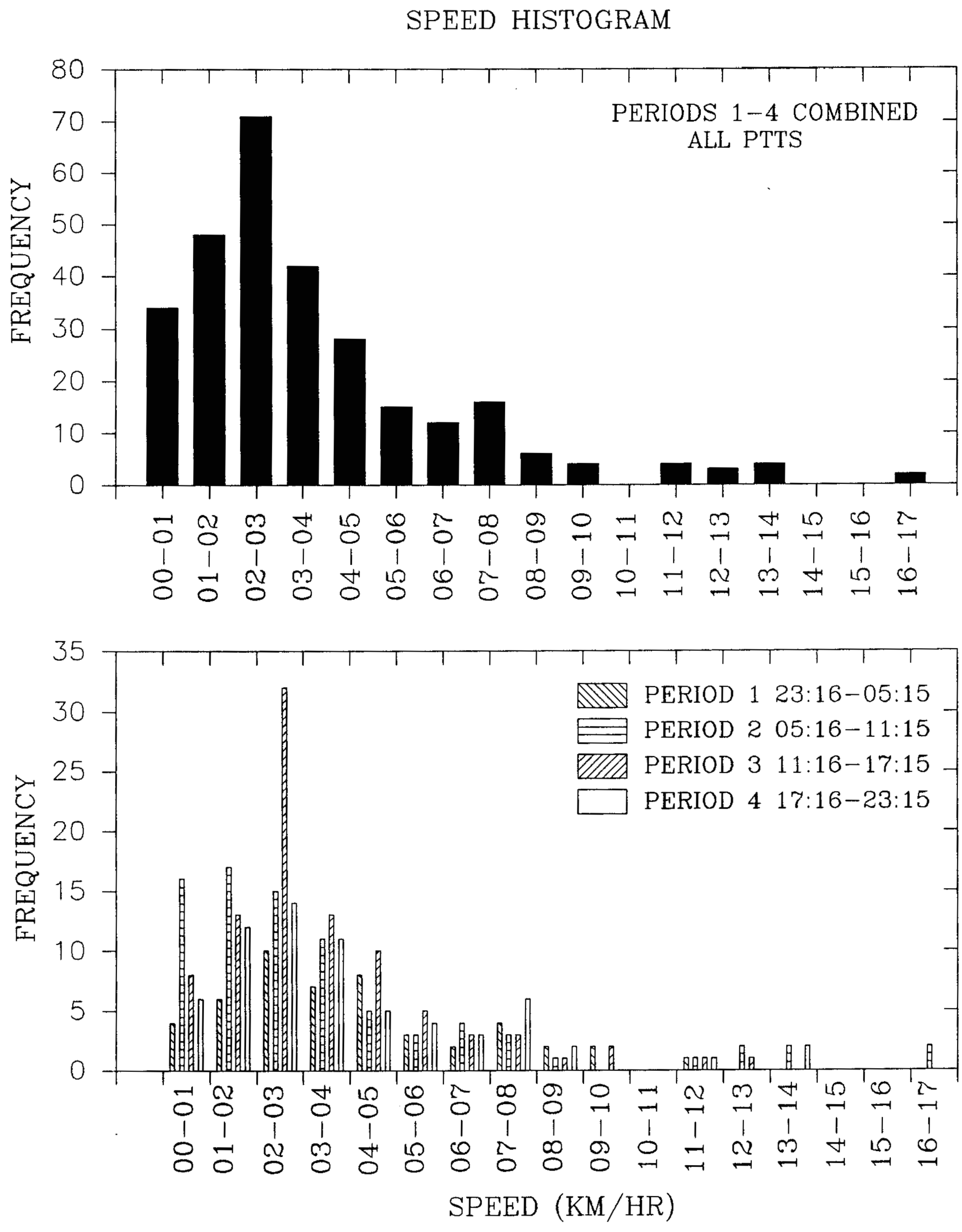


Figure 28. Distribution of minimum travel speeds (km/hr) calculated from Argos-determined locations for PTTs: #823, #825, #833, #839 and #840 tagged in 1990. Times are GMT (Greenwich Mean Time).

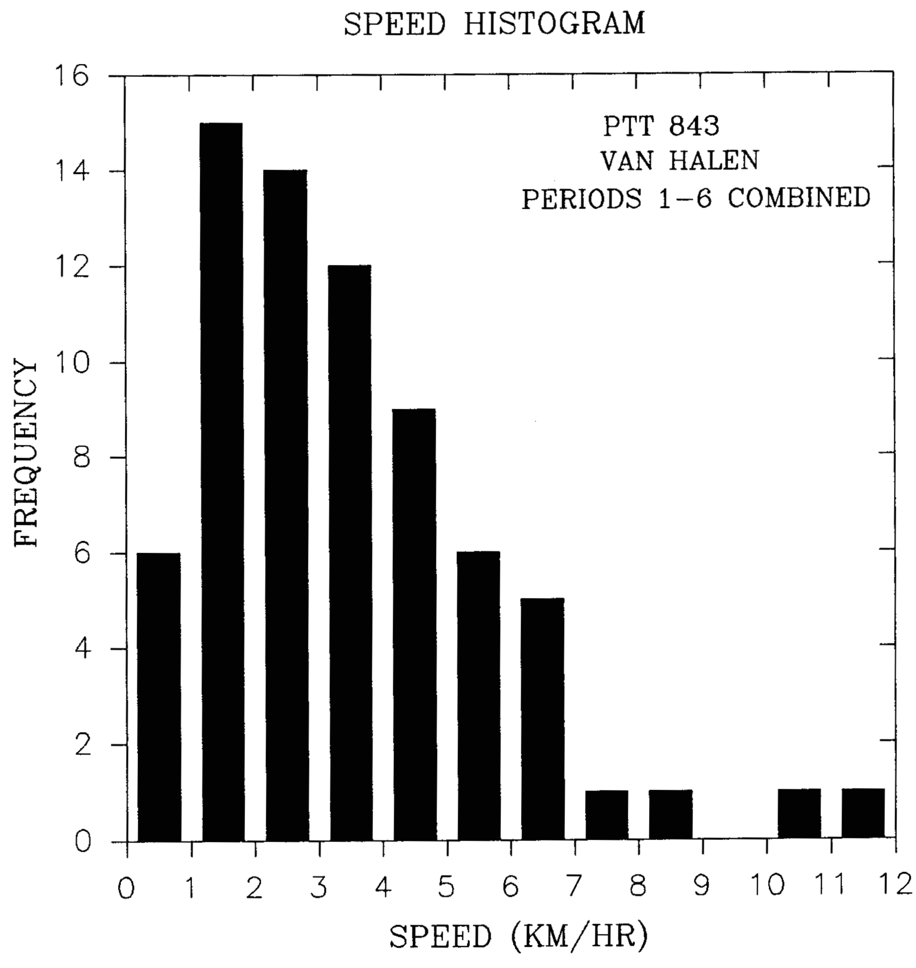


Figure 29. Frequency histogram of minimum travel speeds (km/hr) for PTT #843, an adult male tagged in 1990.

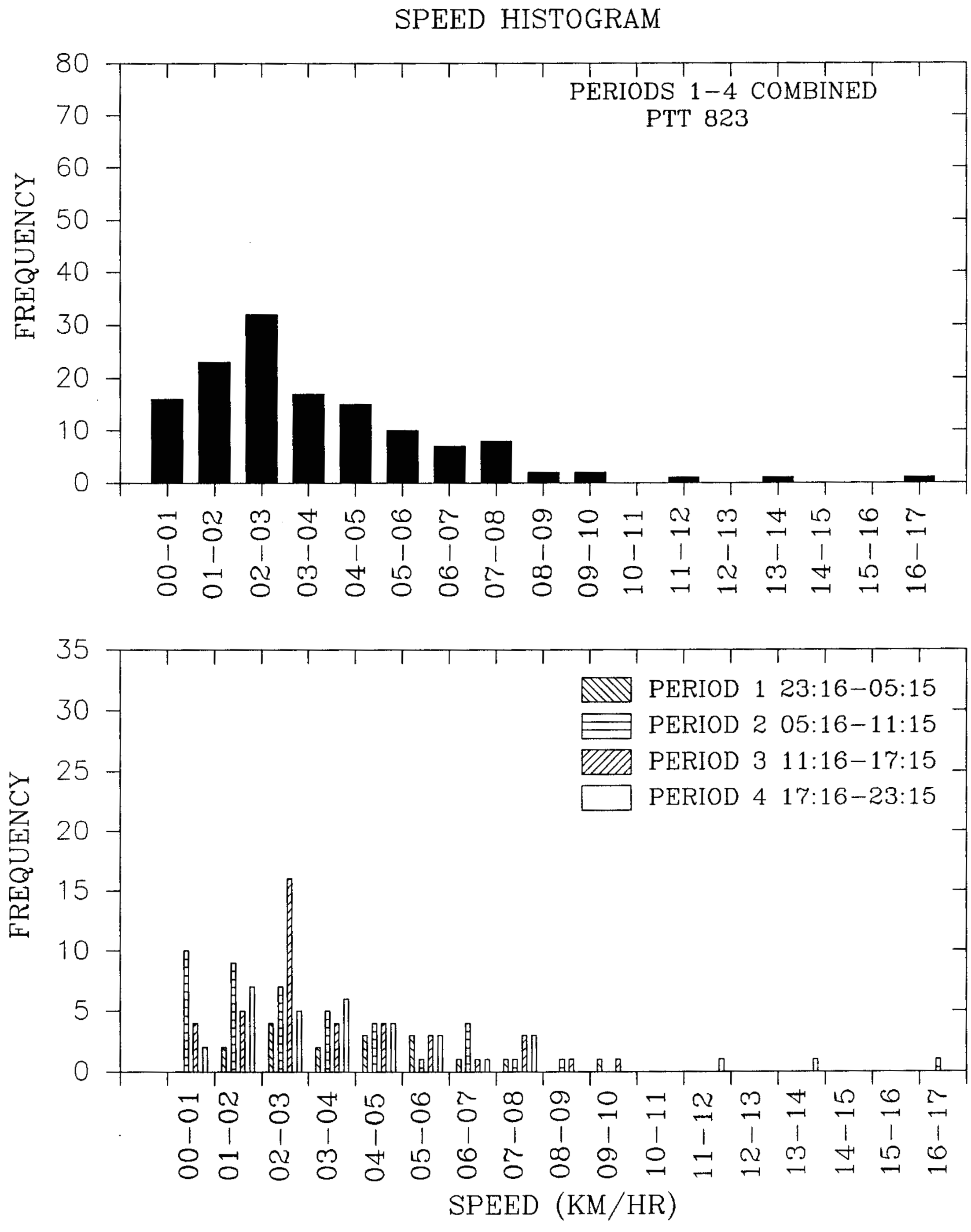


Figure 30. Frequency histogram of minimum travel speeds (km/hr) for PTT #823, an adult male tagged in 1990.

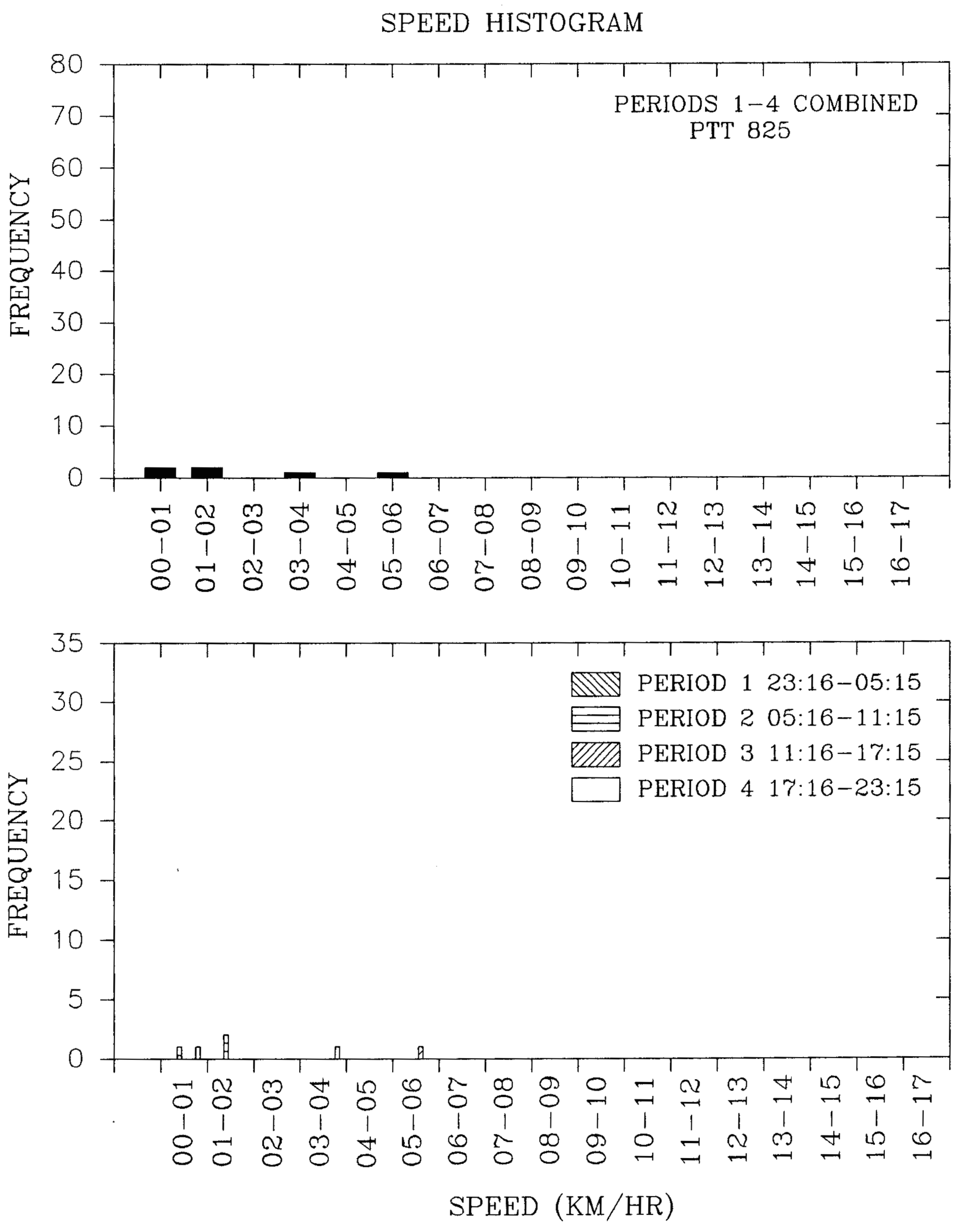


Figure 31. Frequency histogram of minimum travel speeds (km/hr) for PTT #825, an adult female and calf tagged in 1990.

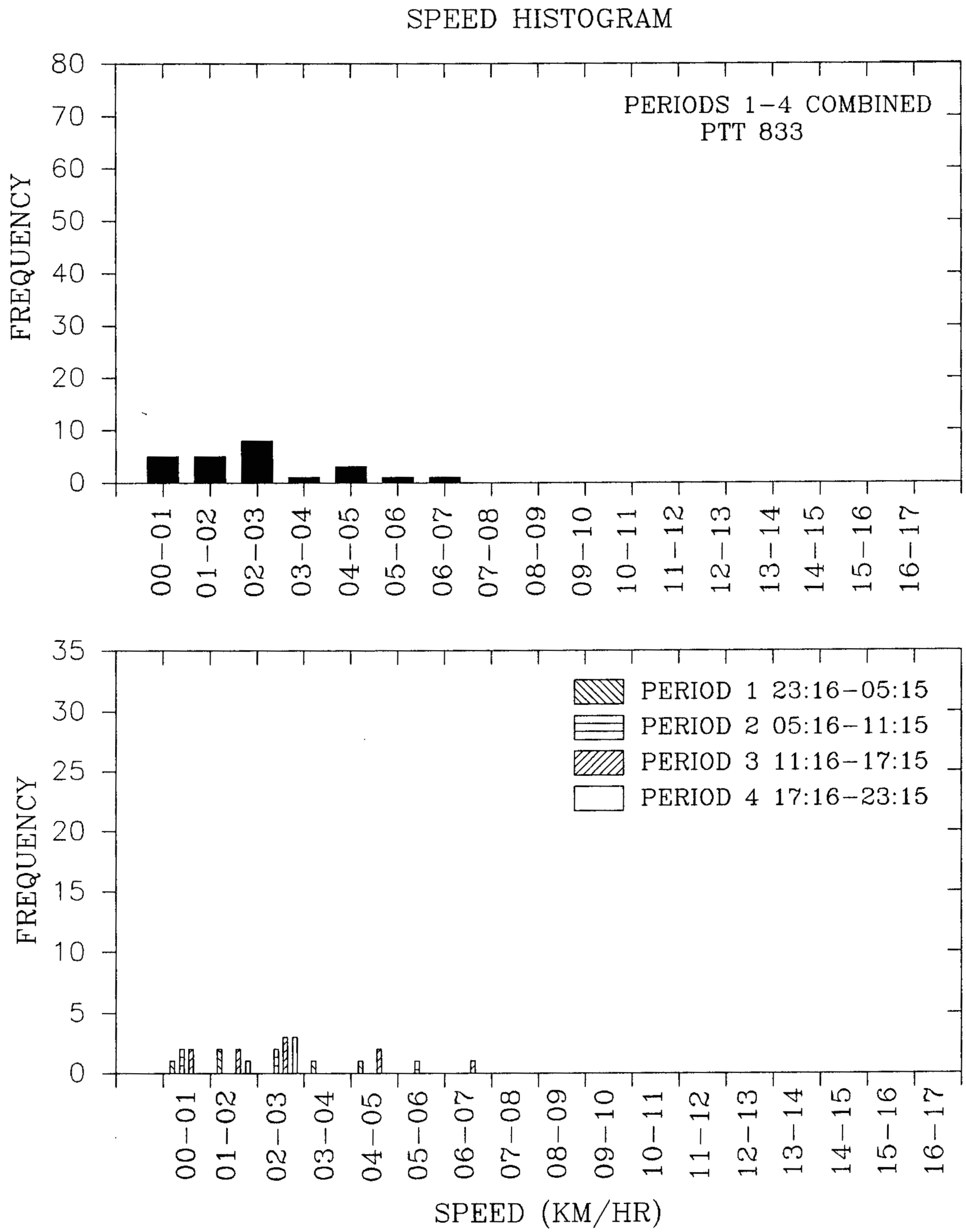


Figure 32. Frequency histogram of minimum travel speeds (km/hr) for PTT #833, a juvenile of unknown sex tagged in 1990.

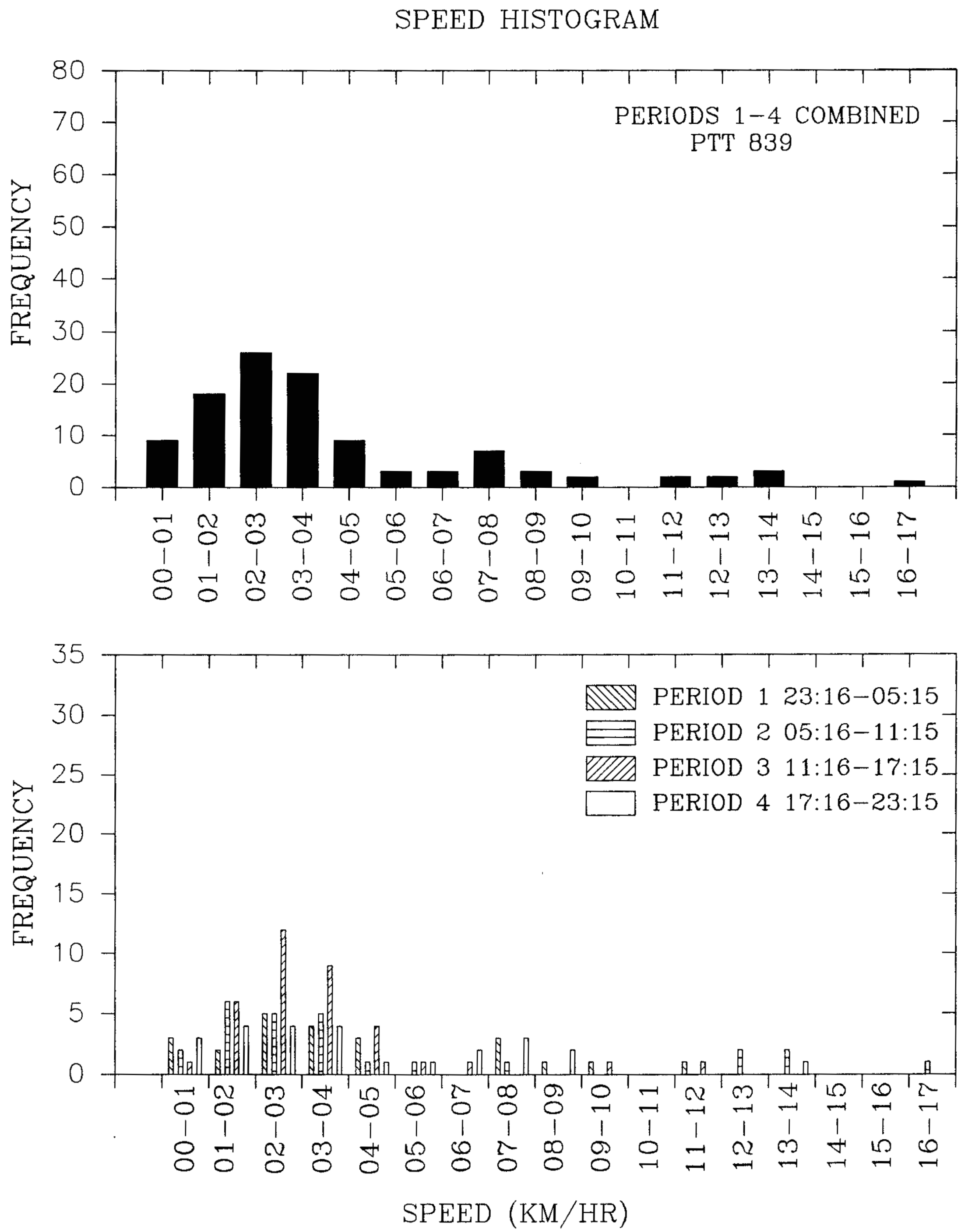


Figure 33. Frequency histogram of minimum travel speeds (km/hr) for PTT #839, an adult female and calf tagged in 1990.

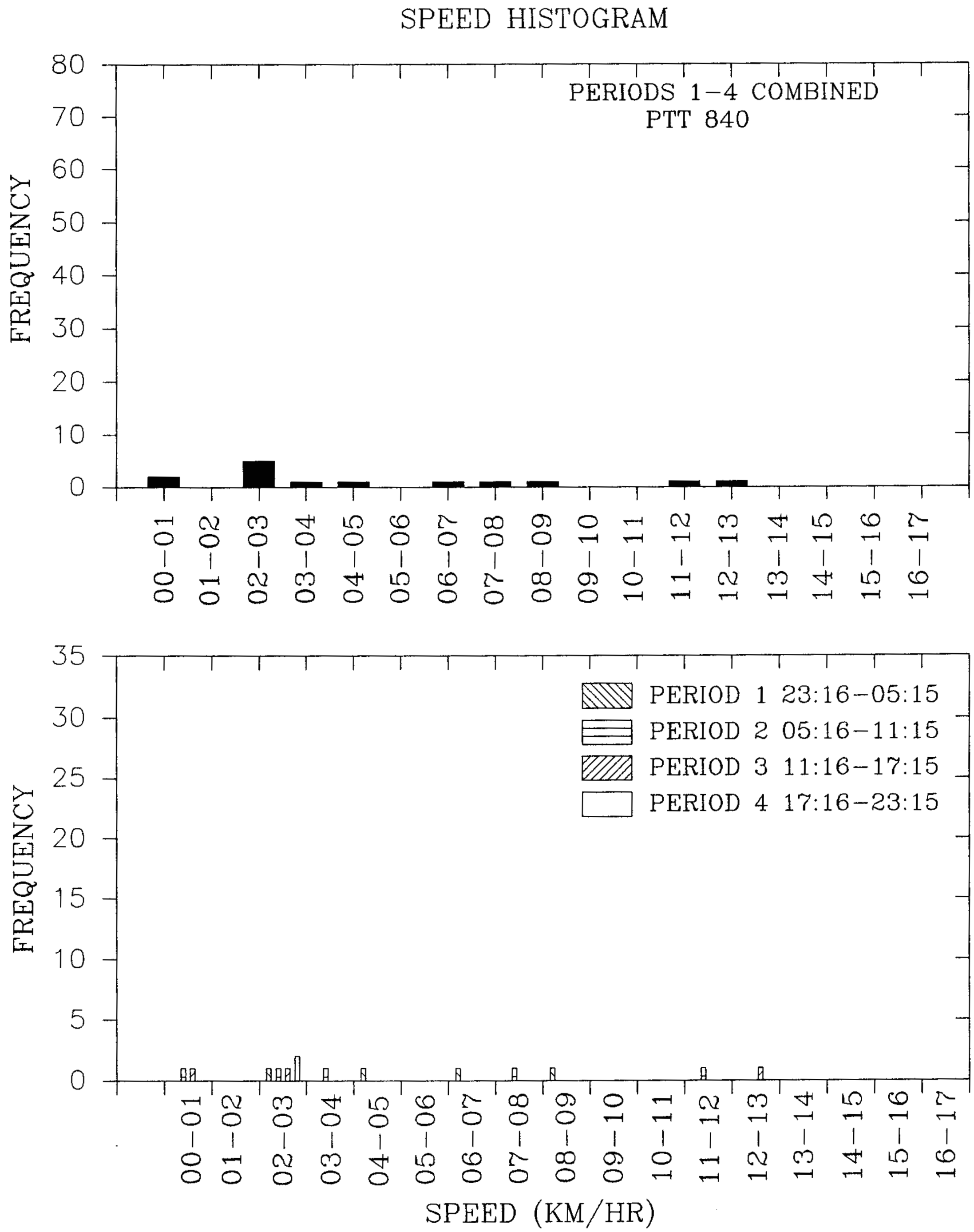


Figure 34. Frequency histogram of minimum travel speeds (km/hr) for PTT #840, a pregnant adult female tagged in 1990.

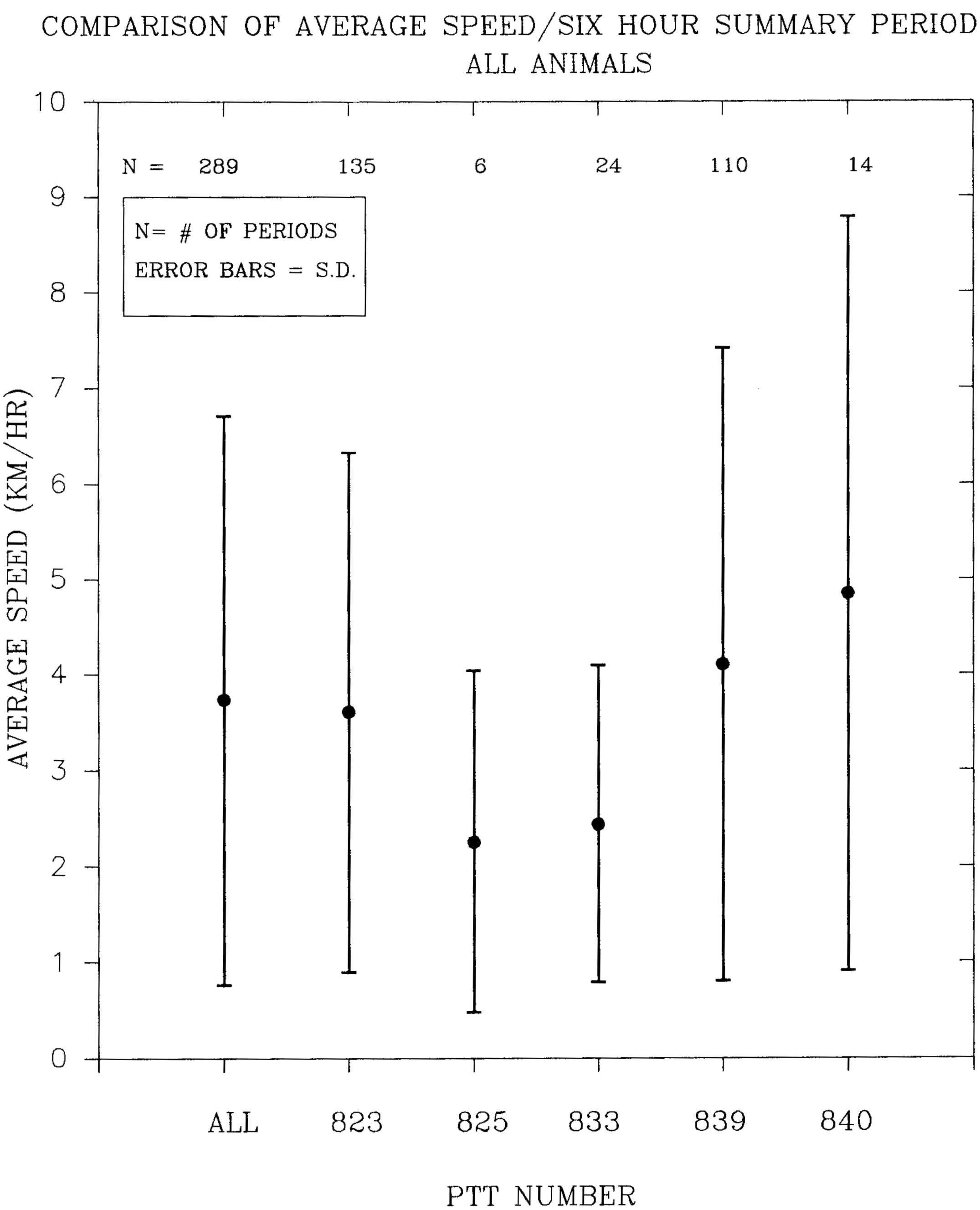


Figure 35. 1990 comparison of average swimming speeds (km/hr +/- 1 sd) during 6-hour summary periods for the five whales with location information. N = number of error-free summary periods used.

Data from locate table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
speed ave	0	3.73	3.61	2.26	---	---	2.44	4.11	4.85
speed count	0	289.00	135.00	6.00	0.00	0.00	24.00	110.00	14.00
speed maximum	0	16.82	16.15	5.34	---	---	6.65	16.82	12.77
speed minimum	0	0.06	0.06	0.71	---	---	0.33	0.55	0.57
speed stdev	0	2.97	2.71	1.63	---	---	1.62	3.29	3.80
speed ave	1	4.15	4.40	---	---	---	2.24	4.17	5.33
speed count	1	49.00	17.00	0.00	0.00	0.00	5.00	23.00	4.00
speed maximum	1	11.11	9.96	---	---	---	4.48	11.11	8.73
speed minimum	1	0.55	1.37	---	---	---	0.61	0.55	2.10
speed stdev	1	2.61	2.25	---	---	---	1.41	2.86	2.43
speed ave	2	3.69	3.17	1.38	---	---	2.16	4.83	5.18
speed count	2	82.00	43.00	3.00	0.00	0.00	5.00	26.00	5.00
speed maximum	2	16.82	16.15	1.88	---	---	5.24	16.82	11.58
speed minimum	2	0.11	0.11	0.97	---	---	0.33	0.66	0.79
speed stdev	2	3.66	2.94	0.38	---	---	1.78	4.58	3.95
speed ave	3	3.43	3.48	5.34	---	---	2.73	3.35	5.42
speed count	3	92.00	42.00	1.00	0.00	0.00	10.00	36.00	3.00
speed maximum	3	12.77	9.87	5.34	---	---	6.65	11.34	12.77
speed minimum	3	0.42	0.42	5.34	---	---	0.51	0.95	0.57
speed stdev	3	2.38	2.27	0.00	---	---	1.86	2.13	5.28
speed ave	4	3.90	3.94	2.03	---	---	2.30	4.38	2.18
speed count	4	66.00	33.00	2.00	0.00	0.00	4.00	25.00	2.00
speed maximum	4	13.93	13.67	3.36	---	---	2.91	13.93	2.19
speed minimum	4	0.06	0.06	0.71	---	---	1.54	0.78	2.17
speed stdev	4	2.97	2.97	1.32	---	---	0.49	3.21	0.01

Table 7. Speed (km/hr) data summarized by period for whales tagged in 1990. Ave = average speed for the designated period; count = # of summary periods from which statistics were computed; maximum/minimum = maximum/minimum speed during the summary period designated; stdev = standard deviation of the average; period 0 = all periods combined; PTTALL = all PTTs combined. Unable to calculate speed for PTT 827 and 831 due to lack of reliable location data.

Data from locate table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
speed ave	0	3.73	3.61	2.26	---	---	2.44	4.11	4.85
speed ave	1	4.15	4.40	---	---	---	2.24	4.17	5.33
speed ave	2	3.69	3.17	1.38	---	---	2.16	4.83	5.18
speed ave	3	3.43	3.48	5.34	---	---	2.73	3.35	5.42
speed ave	4	3.90	3.94	2.03	---	---	2.30	4.38	2.18
speed count	0	289.00	135.00	6.00	0.00	0.00	24.00	110.00	14.00
speed count	1	49.00	17.00	0.00	0.00	0.00	5.00	23.00	4.00
speed count	2	82.00	43.00	3.00	0.00	0.00	5.00	26.00	5.00
speed count	3	92.00	42.00	1.00	0.00	0.00	10.00	36.00	3.00
speed count	4	66.00	33.00	2.00	0.00	0.00	4.00	25.00	2.00
speed maximum	0	16.82	16.15	5.34	---	---	6.65	16.82	12.77
speed maximum	1	11.11	9.96	---	---	---	4.48	11.11	8.73
speed maximum	2	16.82	16.15	1.88	---	---	5.24	16.82	11.58
speed maximum	3	12.77	9.87	5.34	---	---	6.65	11.34	12.77
speed maximum	4	13.93	13.67	3.36	---	---	2.91	13.93	2.19
speed minimum	0	0.06	0.06	0.71	---	---	0.33	0.55	0.57
speed minimum	1	0.55	1.37	---	---	---	0.61	0.55	2.10
speed minimum	2	0.11	0.11	0.97	---	---	0.33	0.66	0.79
speed minimum	3	0.42	0.42	5.34	---	---	0.51	0.95	0.57
speed minimum	4	0.06	0.06	0.71	---	---	1.54	0.78	2.17
speed stdev	0	2.97	2.71	1.63	---	---	1.62	3.29	3.80
speed stdev	1	2.61	2.25	---	---	---	1.41	2.86	2.43
speed stdev	2	3.66	2.94	0.38	---	---	1.78	4.58	3.95
speed stdev	3	2.38	2.27	0.00	---	---	1.86	2.13	5.28
speed stdev	4	2.97	2.97	1.32	---	---	0.49	3.21	0.01

Table 8. Speed data summarized by category and PTT. See note Table 7 for details.

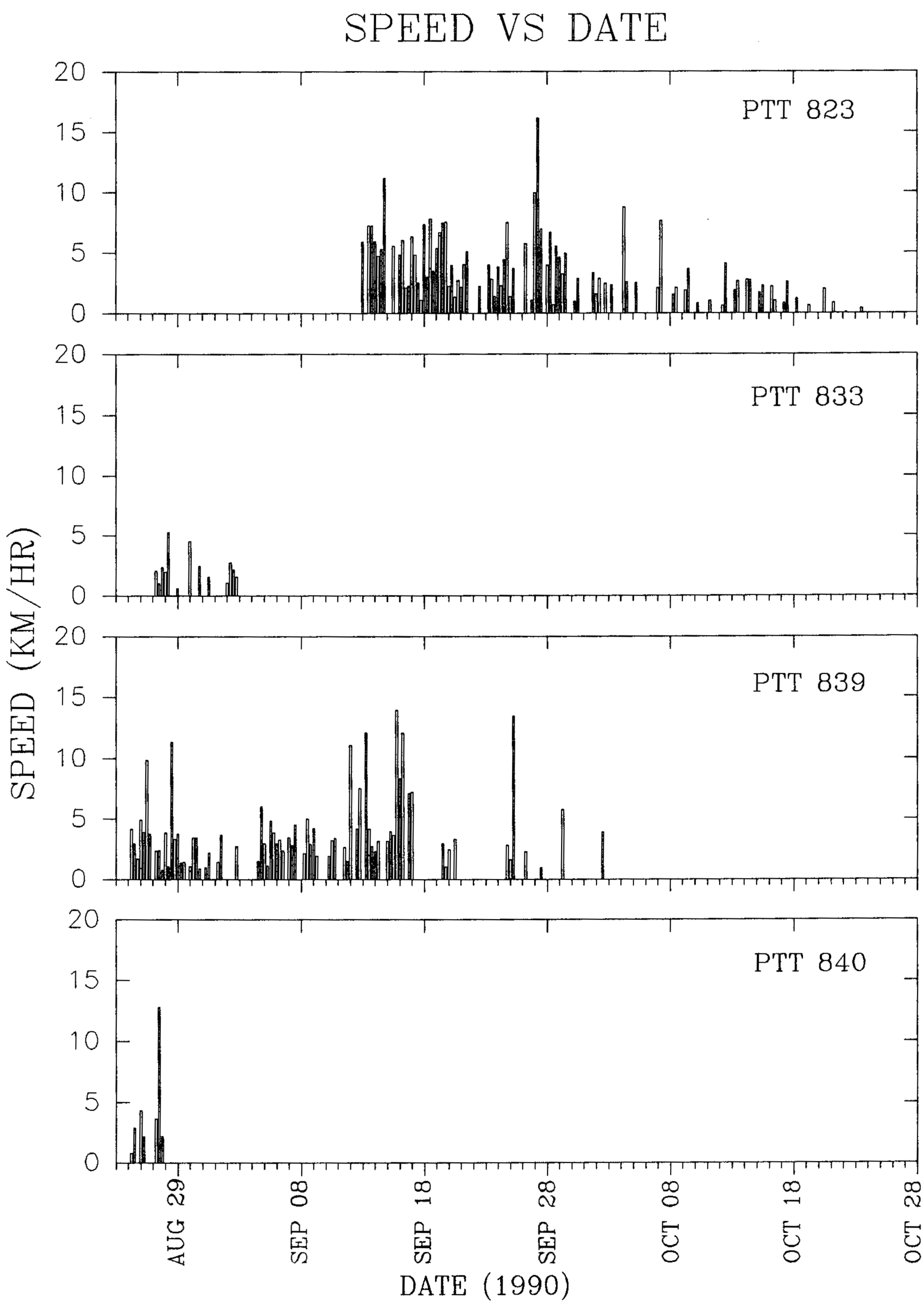


Figure 36. Chronological comparison of speeds (km/hr) during the 1990 tracking study for PTTs #823, #833, #839 and #840. Bars represent speed during a 6-hour summary period.

Diving Behavior

During 160 whale-track days, summary data were recorded on 92,963 dives (12,209 in 1989 and 80,754 in 1990). The only two summary items recorded in like fashion for 1989 and 1990 were the number of dives and the average dive duration during 4 and 6-hour summary periods, respectively. This section will: 1) review these data; 2) discuss two subsets of the data: zero duration "dives" (surface resting behavior) and the time spent submerged; and 3) examine the relationship between speed of travel and dive patterns.

Number of dives

1989

The number of dives in a 4-hour summary period for PTT #843 varied from 117 to 403 with an average of 182 $\pm$ 57 (45.2/hr. see Figure 39). Allowing for a 3 s surface time, this provided an average dive duration of 75 s compared to an average of 74 s for discrete dive information from the same animal.

The average number of dives was generally consistent for all areas and periods (Figure 40). The highest average number of dives (227 $\pm$ 84) occurred east of Jeffrey's Ledge between 0400 - 0800 GMT (2300 to 0300 EST), during darkness. The second highest average number of dives (204 $\pm$ 64) occurred on Brown's Bank between 2000 and 2400 GMT (1500 - 1900 EST) and is 40% higher than all other periods of the day for that region. This period includes dusk, which is when the deep scattering layer (DSL) first appears near the surface and may, therefore, be the start of more active shallow feeding.

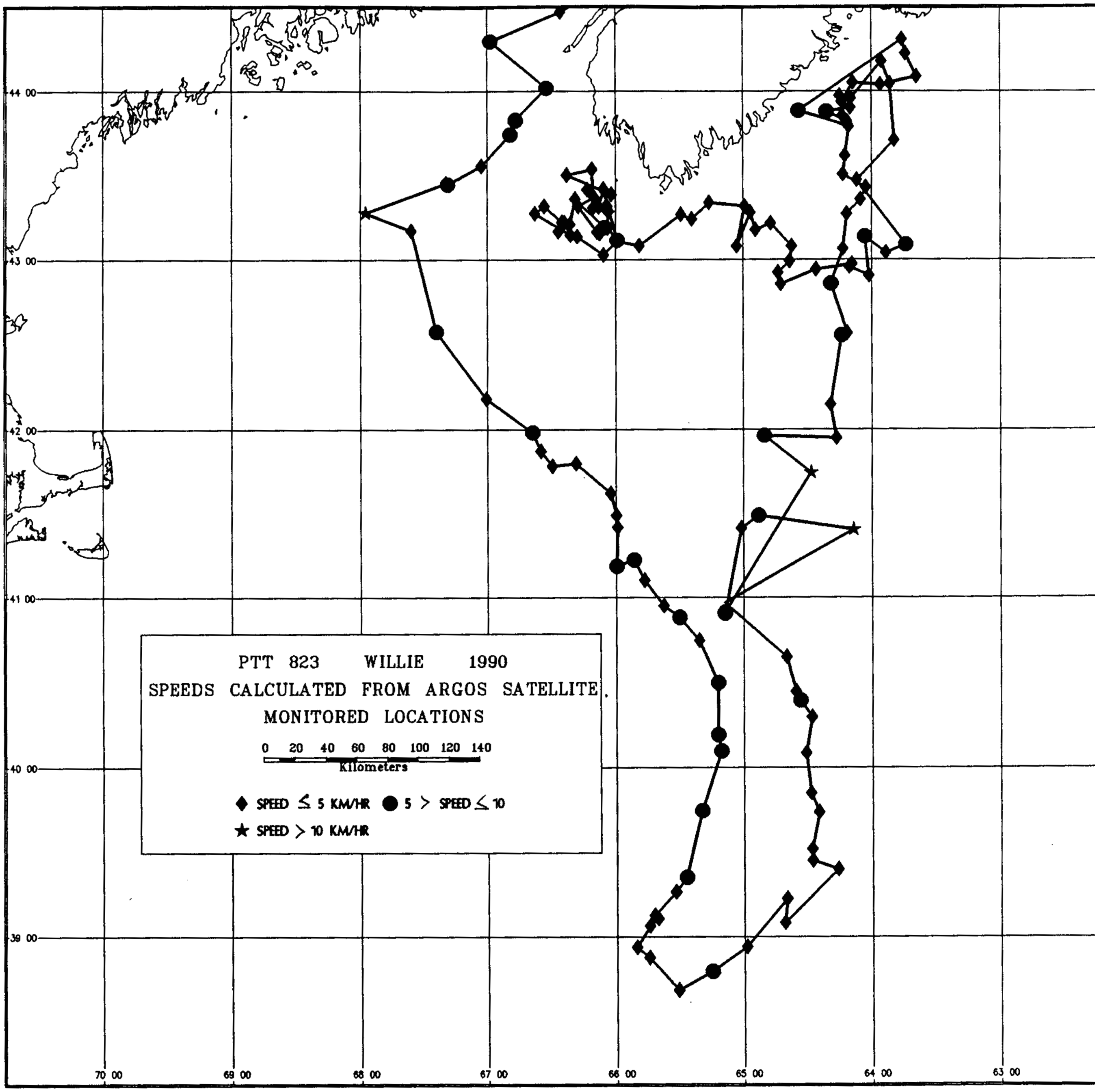


Figure 37. Speeds calculated from Argos satellite-monitored locations for PTT #823, a known adult male.

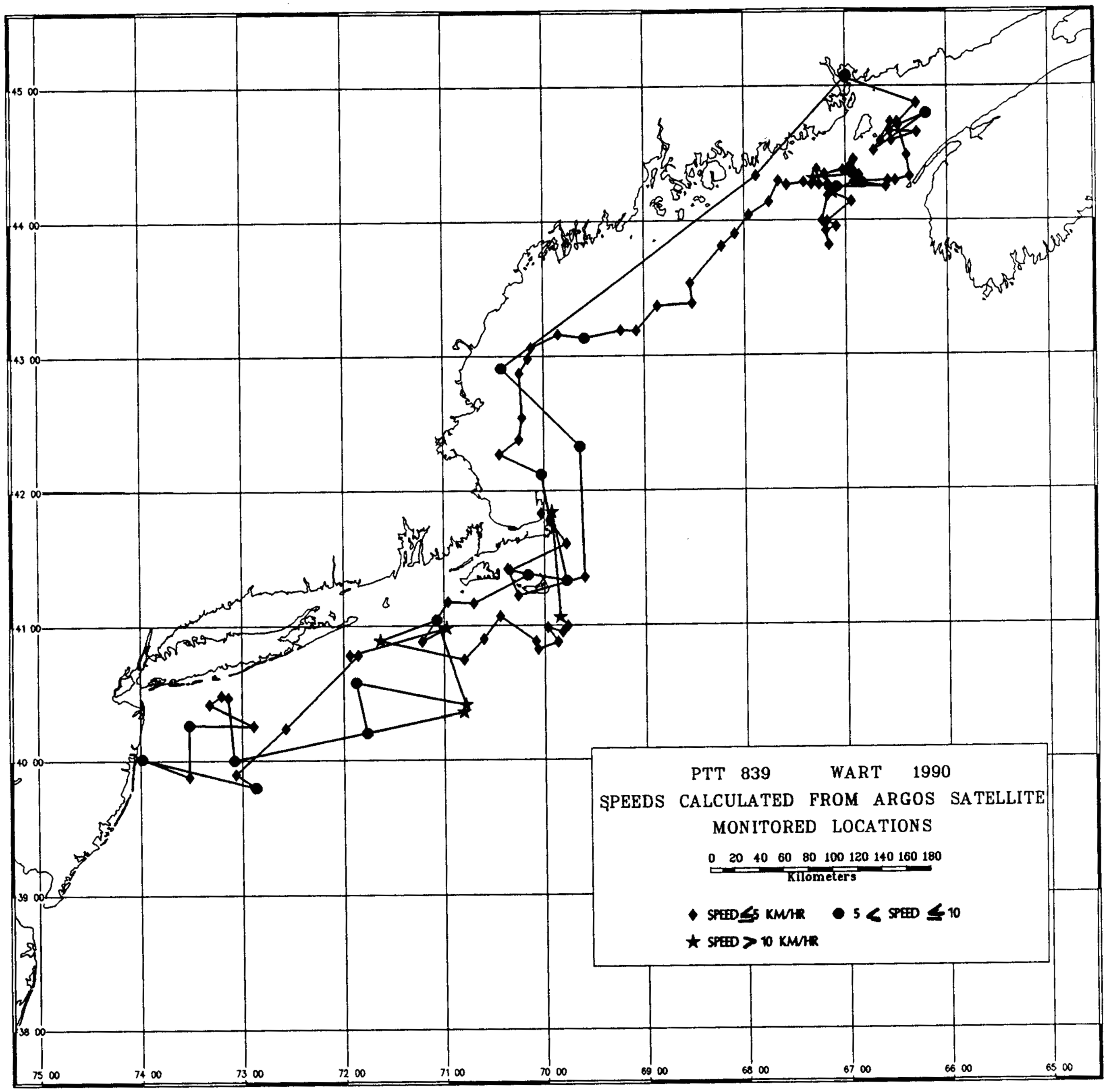


Figure 38. Speeds calculated from Argos satellite-monitored locations for PTT #839, a known female with a 1990 calf.

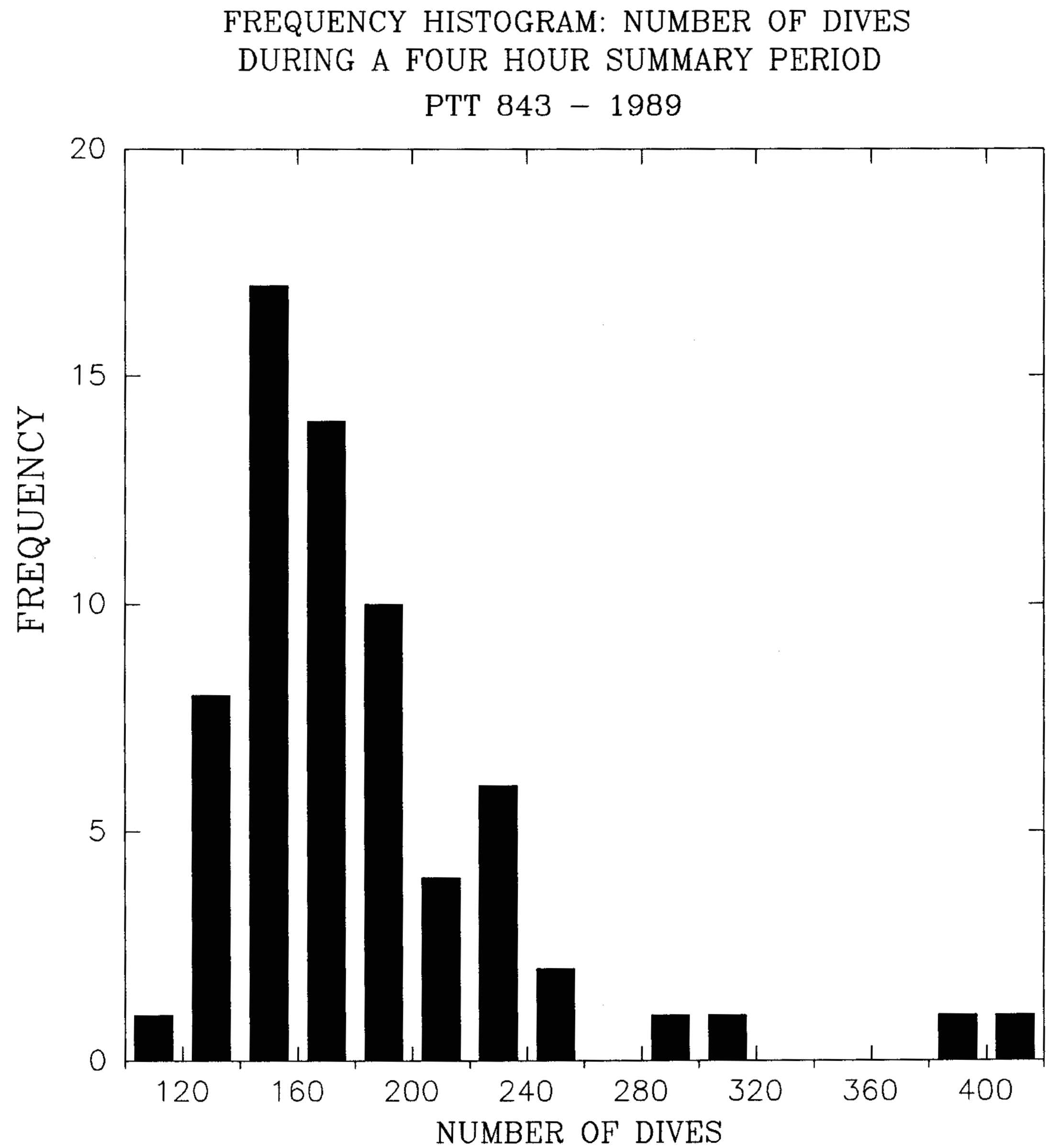


Figure 39. Frequency histogram of number of dives during a 4-hour summary period for PTT #843 (1989).

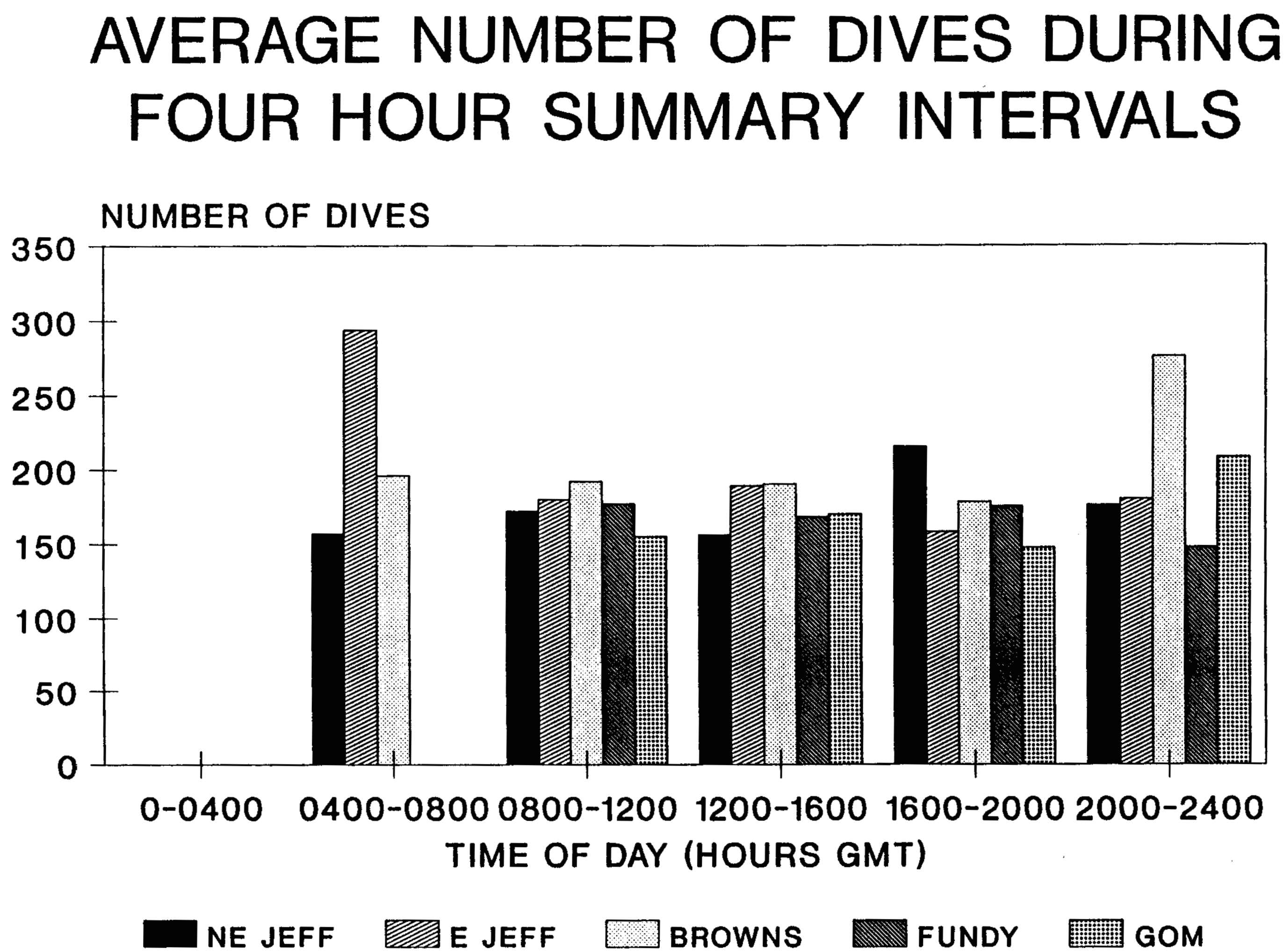


Figure 40. Comparison of average number of dives during 4-hour summary periods grouped by time of day and geographic area, for a male right whale tagged in 1989 (PTT #843).

1990

A statistical analysis of the 80,754 dives recorded during 6-hour summary periods is shown in Tables 9 and 10. The data are depicted graphically in Figure 41. The number of dives during a six hour period ranged from 55 to 920. Frequency histograms of the number of dives/six hour period are shown for all whales combined (Figure 42) and each individual whale (Figures 43 - 49).

The average number of dives in a 6-hour period for all animals was 268 $\pm$ 159 dives ($\bar{x}$ = 44.6/hr.). Individually, "Willie" (PTT #823) had a highest average number of dives ($\bar{x}$ = 384 $\pm$ 181). His 66 dives/hour were 43% higher than "Van Halen" (PTT #843), another adult male tagged in 1989. The maximum count for PTT #823 ranged from 698 to 920 dives for the different periods while the maximum for all other whales was no higher than 413. The highly mobile female with a calf, "Wart" (PTT #839), averaged only half as many dives (192 dives $\pm$ 54) per period ($\bar{x}$ = 32/hr.) as PTT #823, despite a comparable distance traveled. The periods with very high numbers of dives for PTT #823 occurred on 21 September coinciding with the animal's most southerly travel into an area of deep, warm water at the edge of the Gulf Stream.

The juvenile (PTT #833) and female with a calf (PTT #839) had an identical mean number of dives. The fastest moving female (PTT #840) showed one of the lowest average number of dives per period ($\bar{x}$ = 139 dives $\pm$ 96). The lowest number of dives was shown by a two year old (PTT #827) with a mean of 126 $\pm$ 7 but may have been due to the extremely small sample size (n = 5). For four of the six whales, the highest number of dives occurred during the period from mid-day to dusk (Period 4) and the lowest number of dives occurred during the period from midnight to dawn (Period 2).

Both PTT #823 (Figure 43) and PTT #839 (Figure 48) have large sample sizes but exhibit different dive distributions. Figures 50 and 51 show the distribution of the number of dives in a six hour period versus the calendar date. The time scale was kept uniform to determine if variations in dive count varied with weather. Only PTT #823 and PTT #839 had sufficient data for comparison and did not show any obvious trends in day to day variation which would reflect changes due to weather.

Data from summary table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
dnum ave	0	268	384	216	126	233	192	192	139
dnum count	0	301	124	7	5	6	26	116	17
dnum maximum	0	920	920	413	138	297	333	341	387
dnum minimum	0	55	70	108	119	204	55	68	55
dnum stdev	0	159	181	91	7	31	67	54	96
dnum sum	0	80754	47591	1510	630	1399	4981	22273	2370
dnum ave	1	269	370	250	130	232	178	180	141
dnum count	1	86	40	3	1	2	7	29	4
dnum maximum	1	885	885	413	130	245	324	289	225
dnum minimum	1	68	79	108	130	218	68	95	82
dnum stdev	1	158	173	125	0	13	82	46	59
dnum ave	2	262	375	135	138	204	161	193	66
dnum count	2	88	38	1	1	1	8	35	4
dnum maximum	2	698	698	135	138	204	217	292	77
dnum minimum	2	55	95	135	138	204	55	68	55
dnum stdev	2	154	167	0	0	0	49	51	7
dnum ave	3	262	364	209	121	207	225	199	137
dnum count	3	76	31	3	2	1	5	29	5
dnum maximum	3	811	811	234	123	207	333	296	286
dnum minimum	3	61	70	182	119	207	166	98	61
dnum stdev	3	155	188	21	2	0	66	57	81
dnum ave	4	286	484	---	120	263	220	196	215
dnum count	4	51	15	0	1	2	6	23	4
dnum maximum	4	920	920	---	120	297	271	341	387
dnum minimum	4	68	134	---	120	228	168	80	68
dnum stdev	4	173	187	---	0	34	36	60	129

Table 9. Number of dives summarized by period for whales tagged in 1990. Ave = average number of dives for the designated period; count = # of summary periods from which statistics were computed; maximum/minimum = maximum/minimum number of dives counted during the summary period designated; stdev = standard deviation of the average; period 0 = all periods combined; PTTALL = all PTTs combined.

Data from summary table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
dnum ave	0	268	384	216	126	233	192	192	139
dnum ave	1	269	370	250	130	232	178	180	141
dnum ave	2	262	375	135	138	204	161	193	66
dnum ave	3	262	364	209	121	207	225	199	137
dnum ave	4	286	484	---	120	263	220	196	215
dnum count	0	301	124	7	5	6	26	116	17
dnum count	1	86	40	3	1	2	7	29	4
dnum count	2	88	38	1	1	1	8	35	4
dnum count	3	76	31	3	2	1	5	29	5
dnum count	4	51	15	0	1	2	6	23	4
dnum maximum	0	920	920	413	138	297	333	341	387
dnum maximum	1	885	885	413	130	245	324	289	225
dnum maximum	2	698	698	135	138	204	217	292	77
dnum maximum	3	811	811	234	123	207	333	296	286
dnum maximum	4	920	920	---	120	297	271	341	387
dnum minimum	0	55	70	108	119	204	55	68	55
dnum minimum	1	68	79	108	130	218	68	95	82
dnum minimum	2	55	95	135	138	204	55	68	55
dnum minimum	3	61	70	182	119	207	166	98	61
dnum minimum	4	68	134	---	120	228	168	80	68
dnum stdev	0	159	181	91	7	31	67	54	96
dnum stdev	1	158	173	125	0	13	82	46	59
dnum stdev	2	154	167	0	0	0	49	51	7
dnum stdev	3	155	188	21	2	0	66	57	81
dnum stdev	4	173	187	---	0	34	36	60	129

Table 10. Average number of dives summarized by statistic category and PTT. See notes on Table 9.

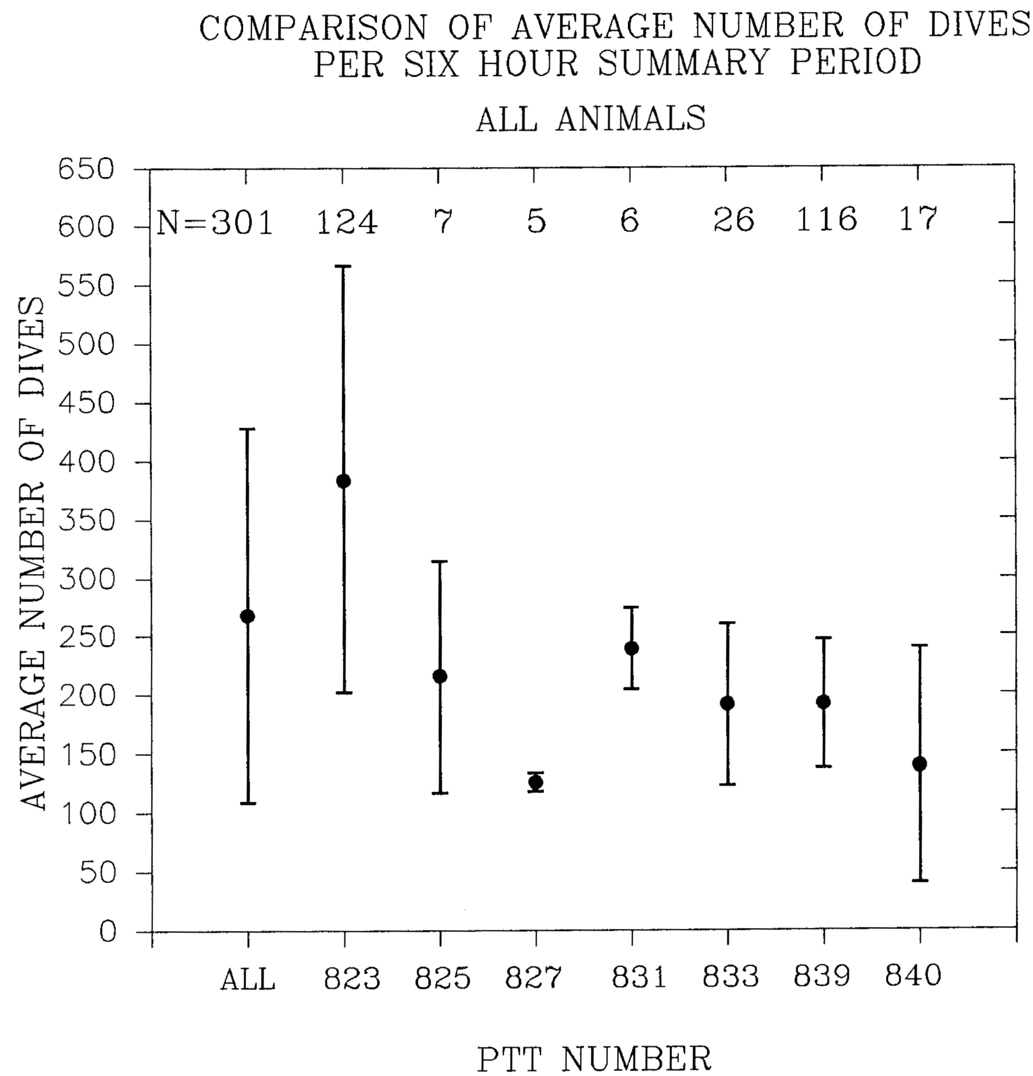


Figure 41. Comparison of average number of dives during a 6-hour summary period for all 1990 animals. A dive is defined as a submergence greater than 6 seconds. N = number of summary periods for which error-free data were collected.

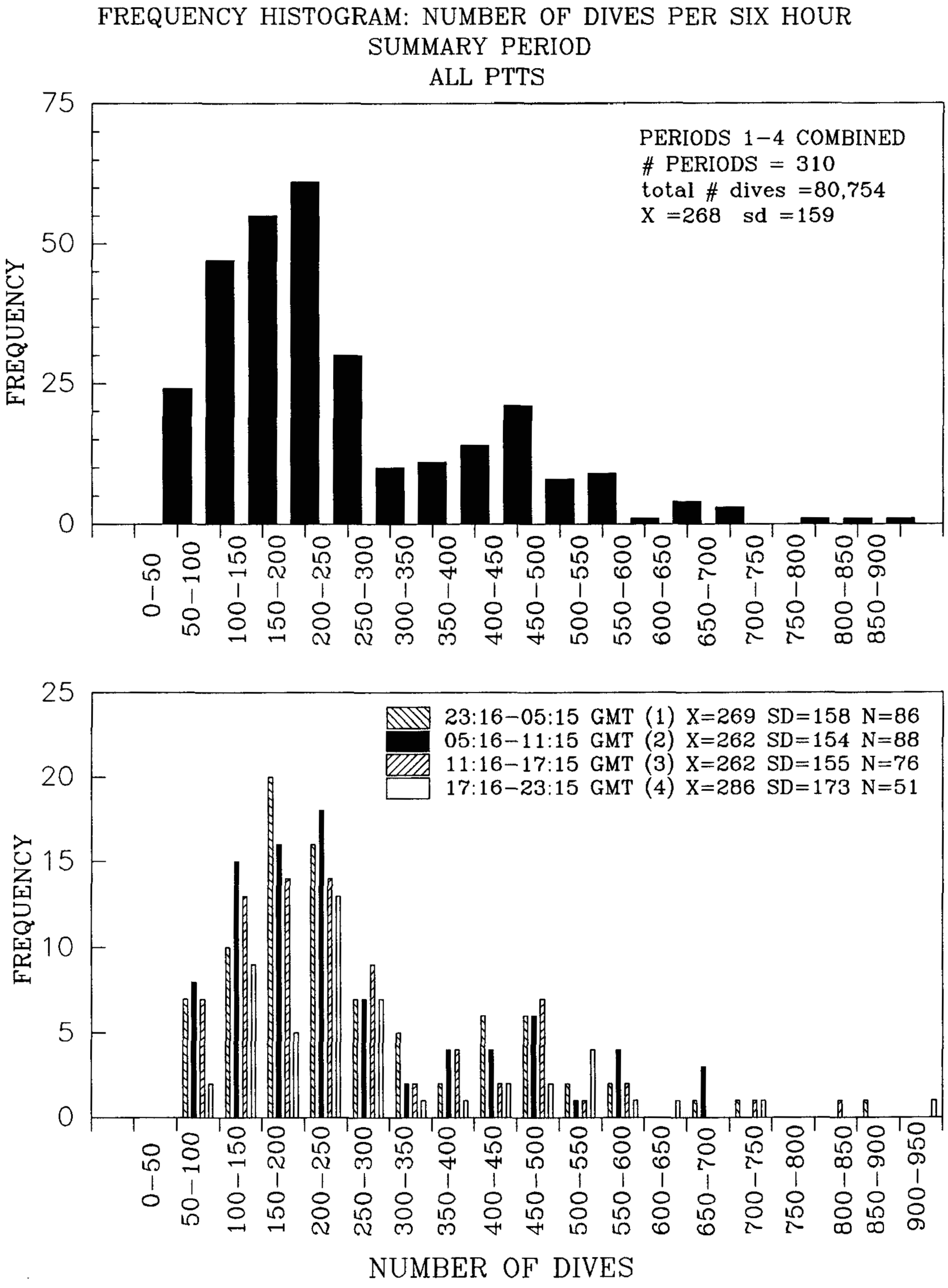


Figure 42. The frequency histogram of the number of dives during 6-hour summary periods for all 1990 PTTs combined (#823, #825, #827, #831, #833, #839, #840). Note: x = mean number of dives during the designated period; sd = standard deviation of the mean; N = # of summary periods from which the histogram was generated.

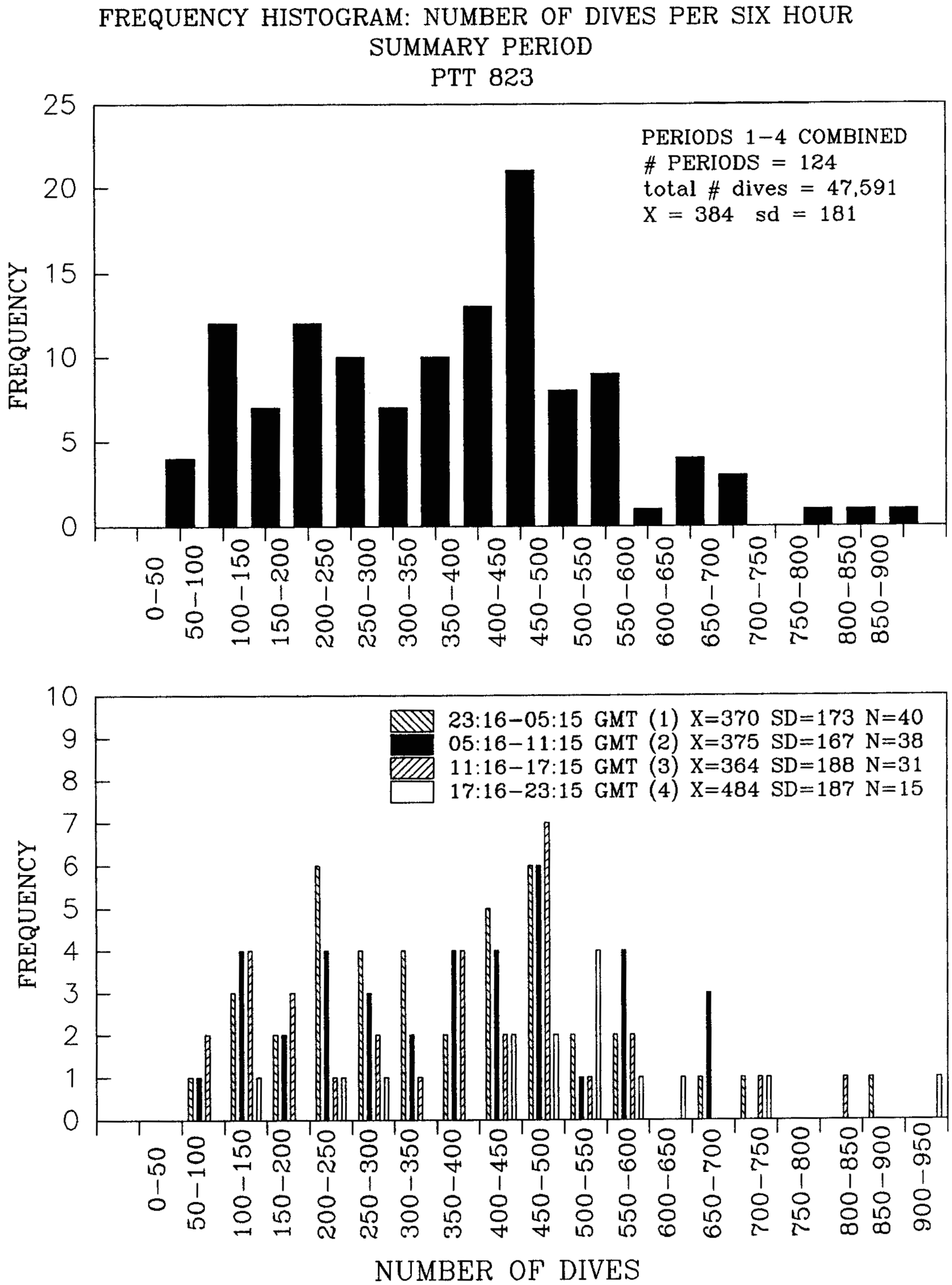


Figure 43. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #823. See note in Figure 42.

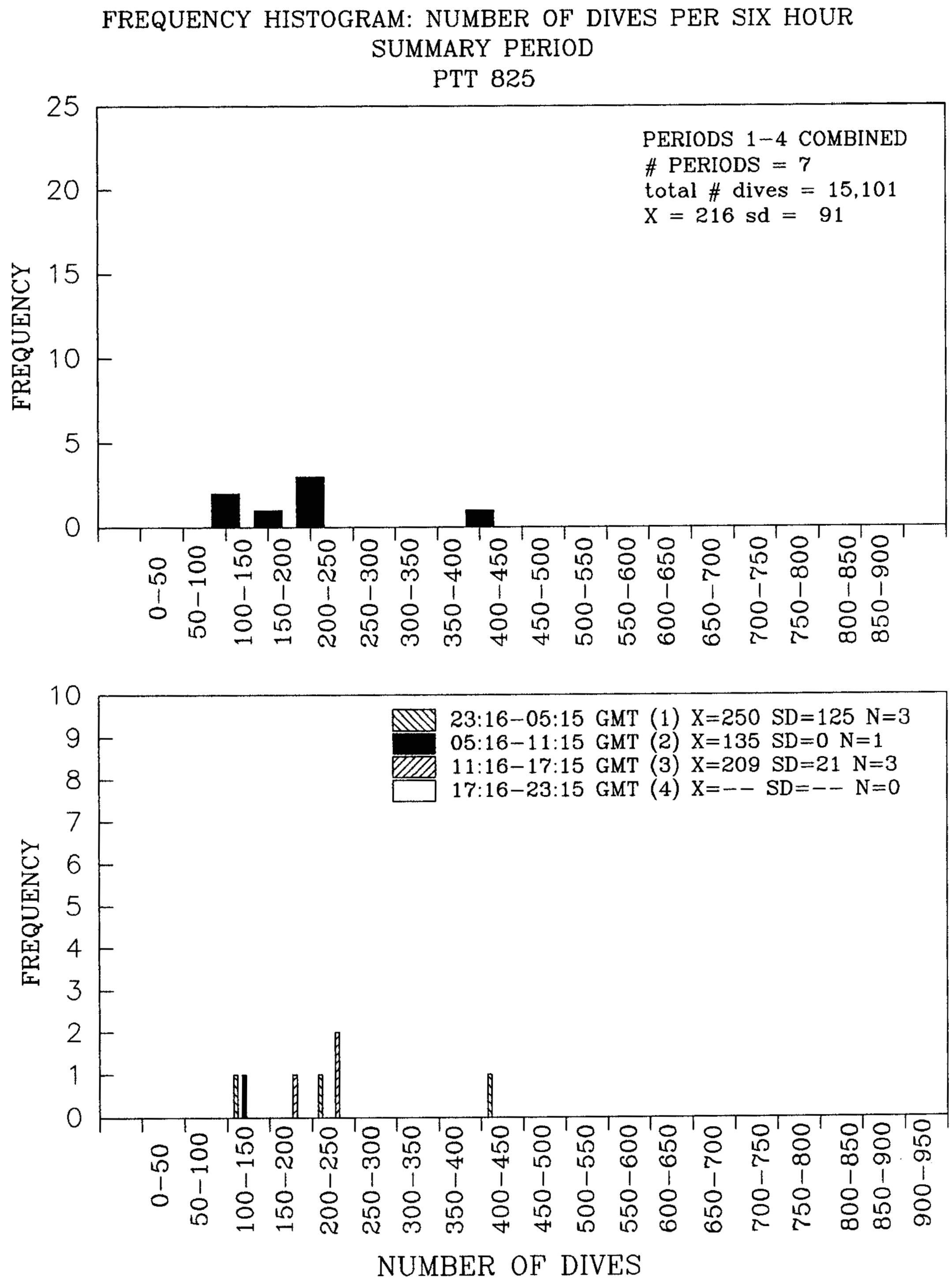


Figure 44. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #825. See note in Figure 42.

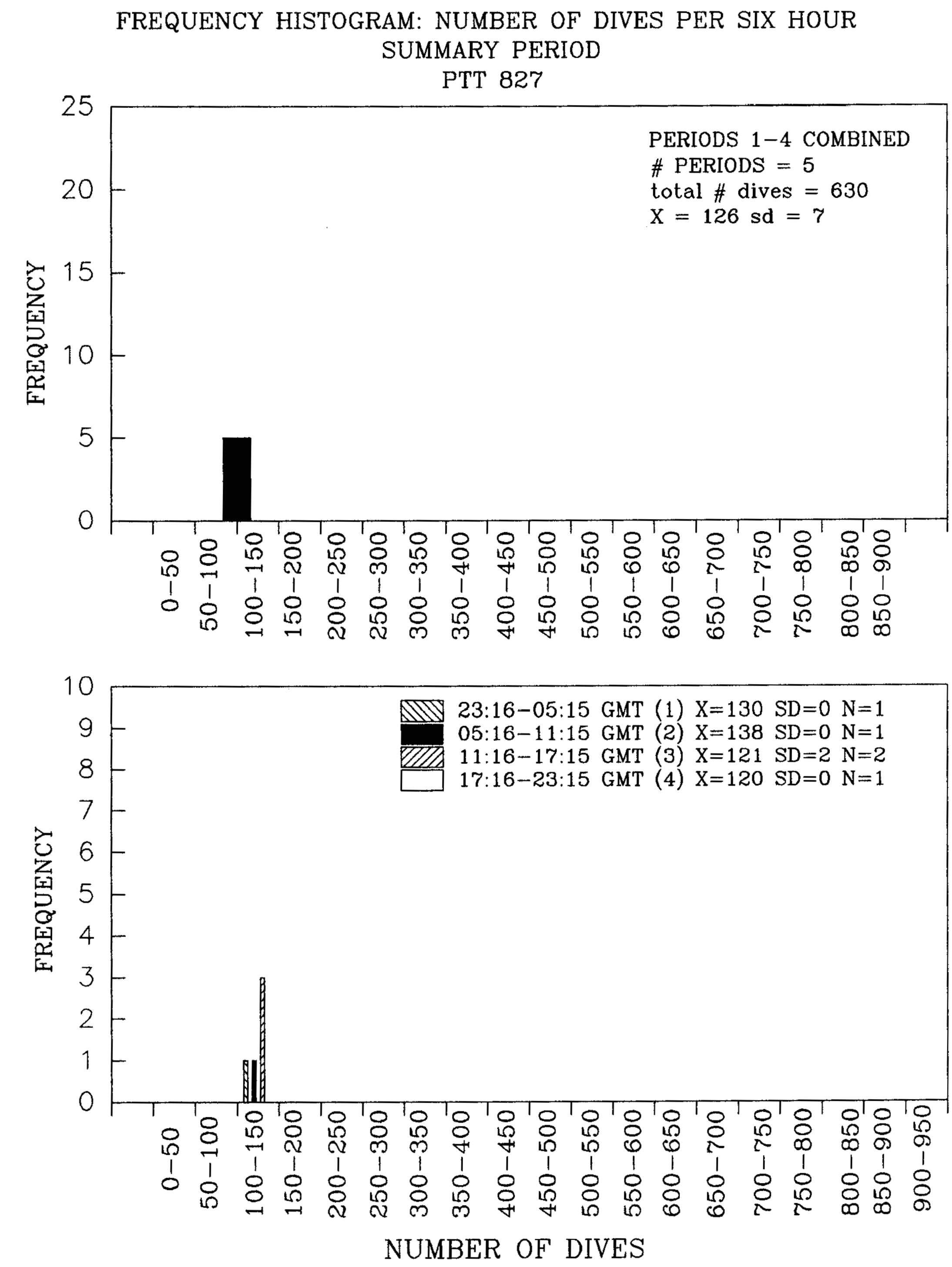


Figure 45. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #827. See note in Figure 42.

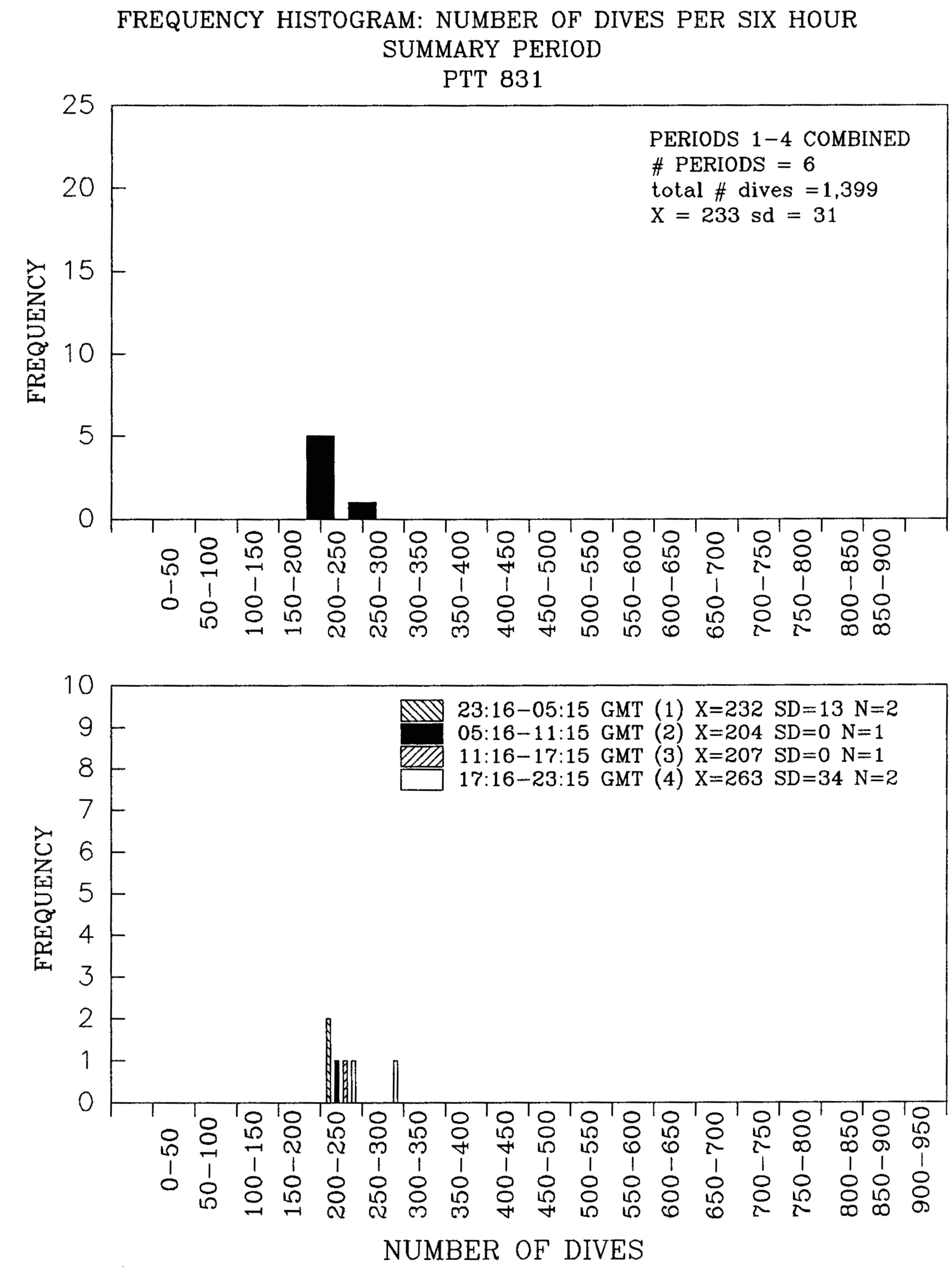


Figure 46. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #831. See note in Figure 42.

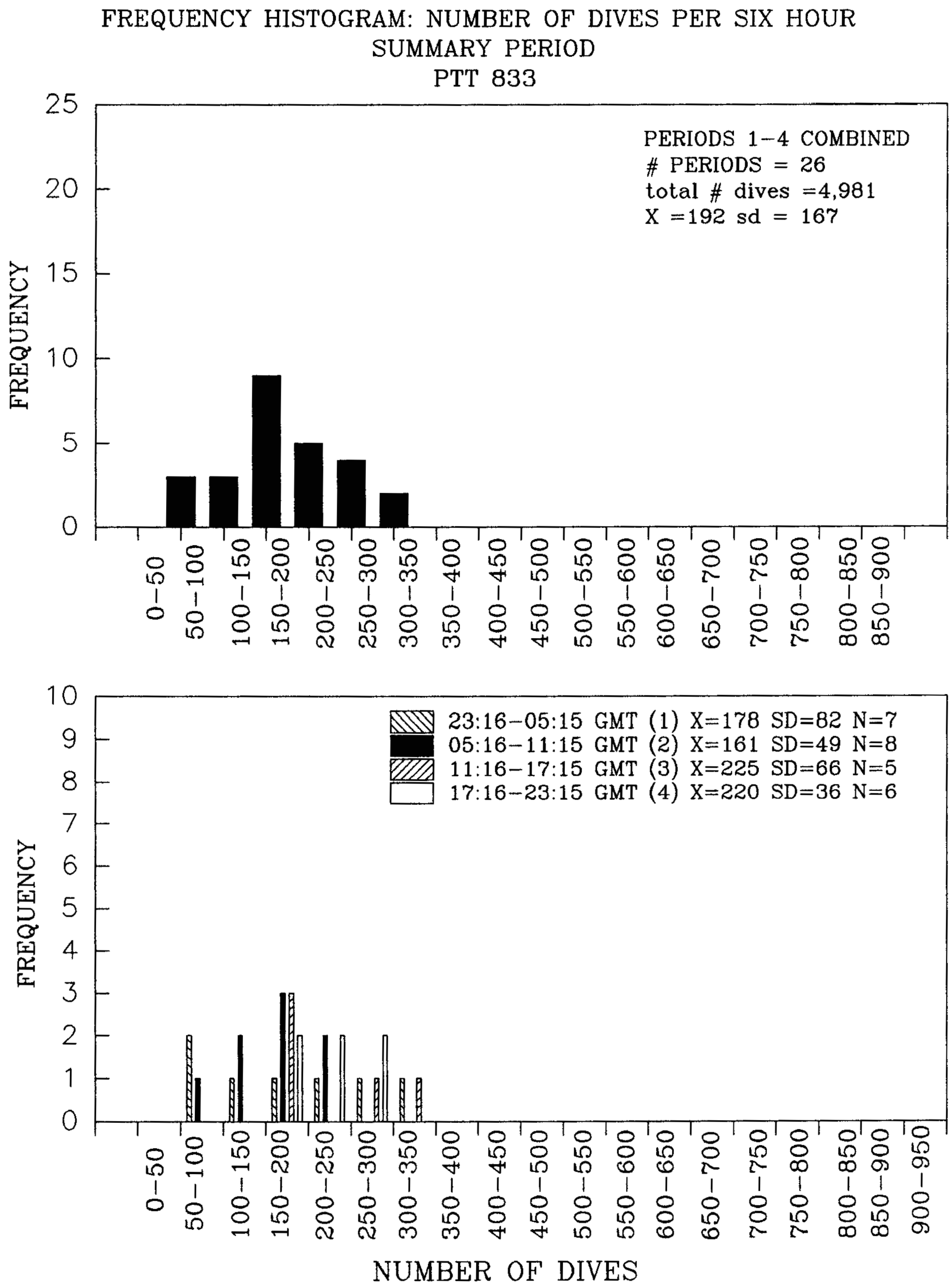


Figure 47. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #833. See note in Figure 42.

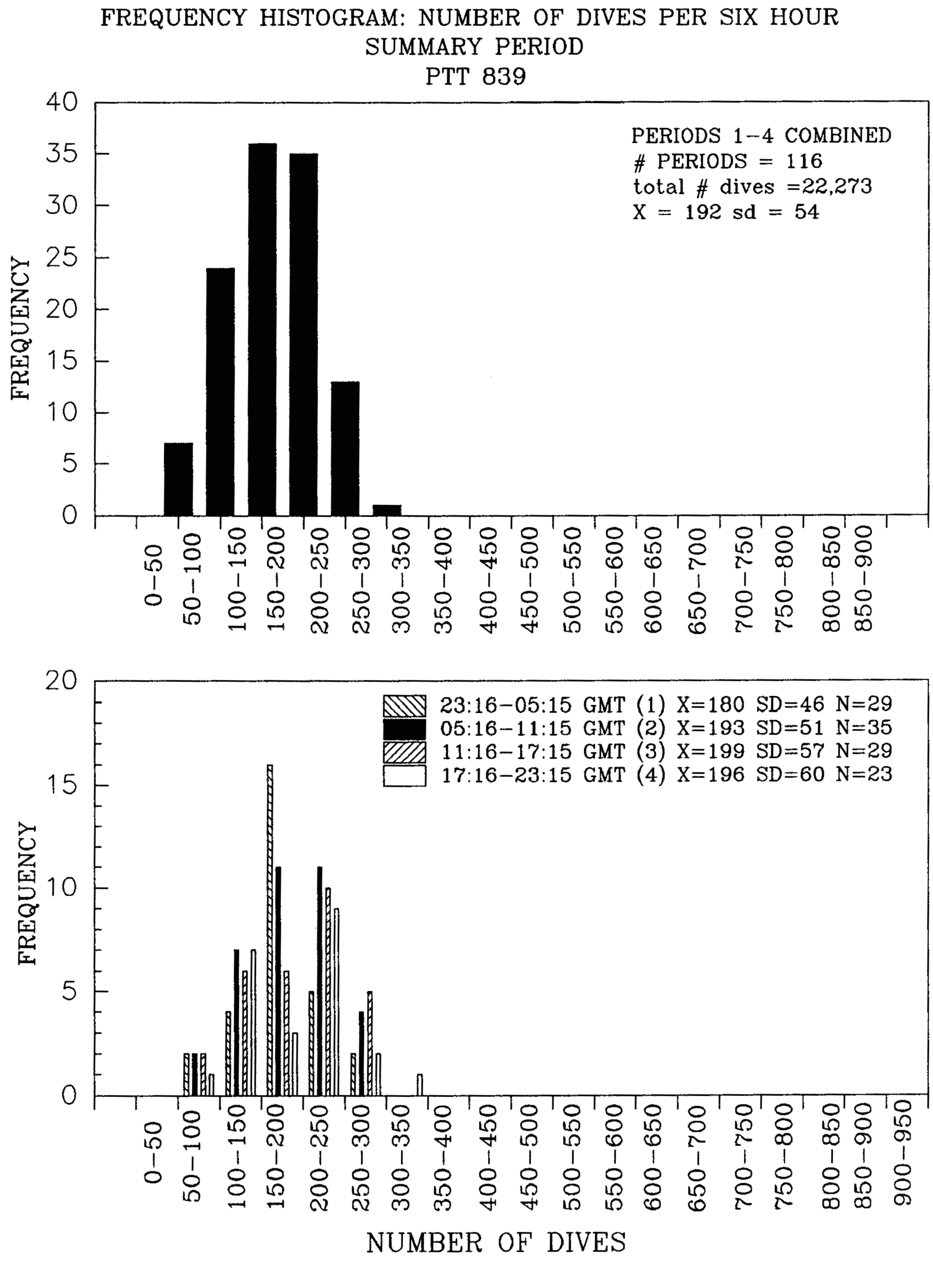


Figure 48. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #839. See note in Figure 42.

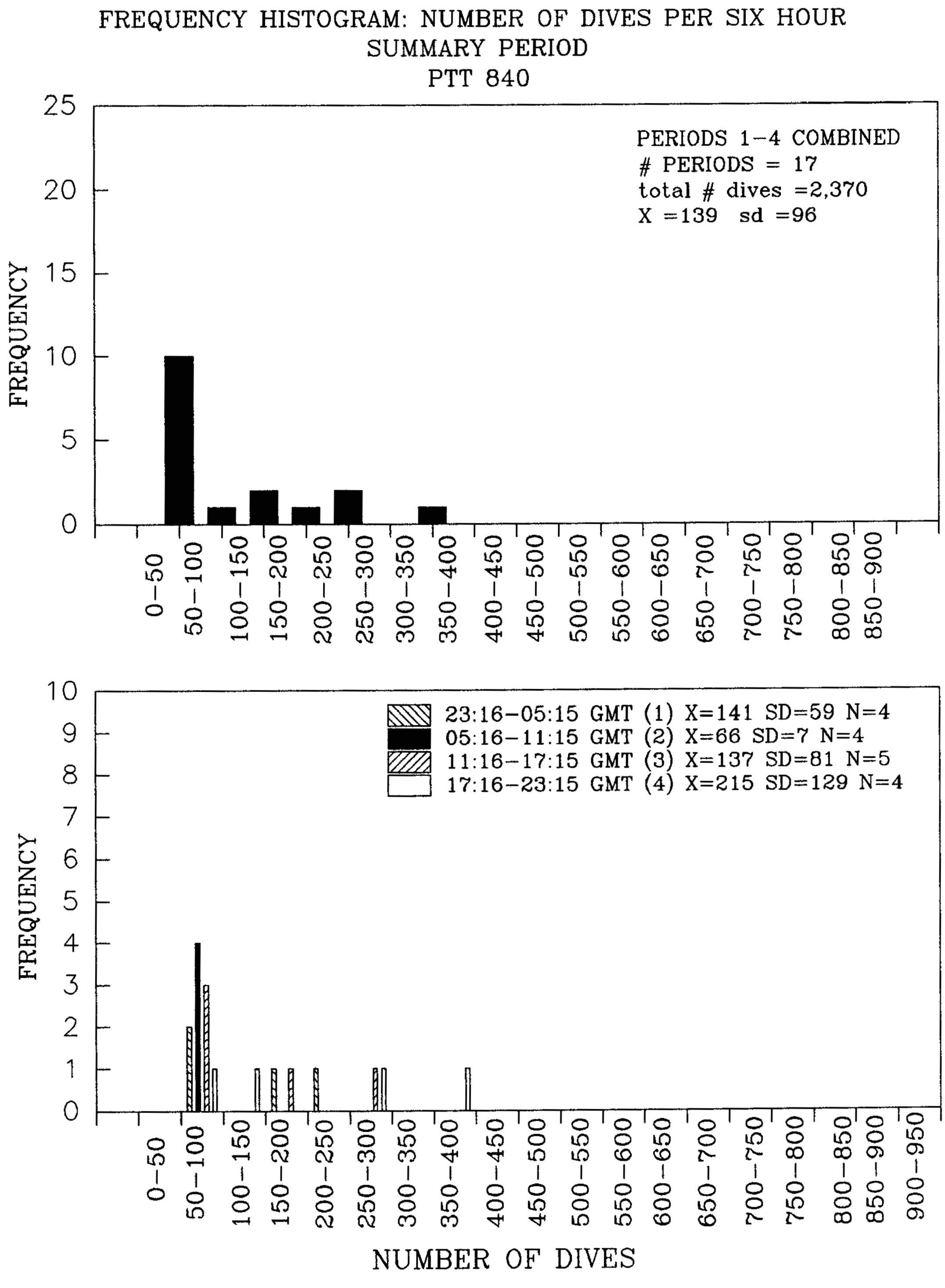


Figure 49. Frequency histogram of the number of dives during all 6-hour summary periods for PTT #840. See note in Figure 42.

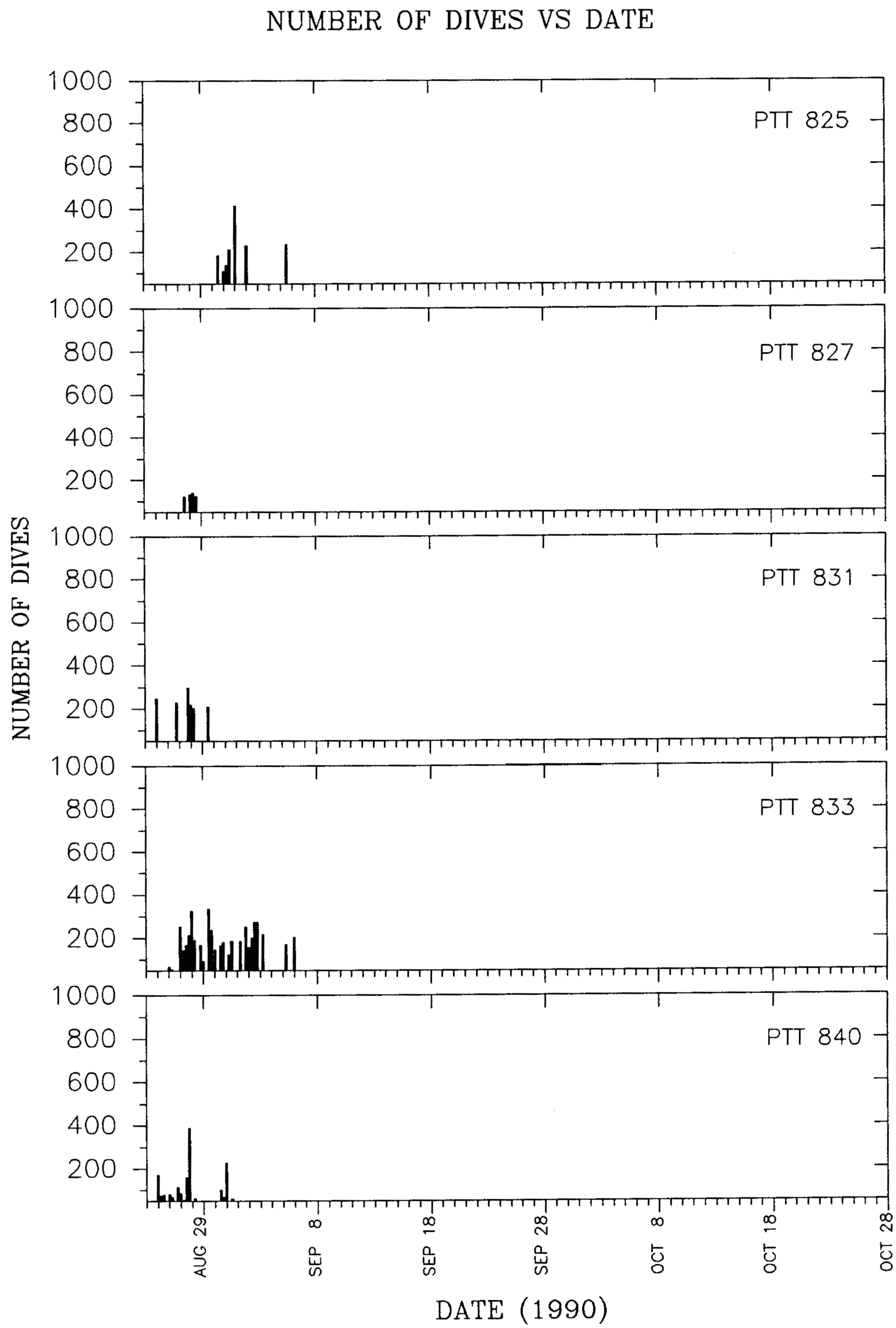


Figure 50. Chronological comparison of number of dives for PTTs #825, #827, #831, #833 and #840 tagged in 1990. Bars represent the number of dives during a 6-hour summary period.

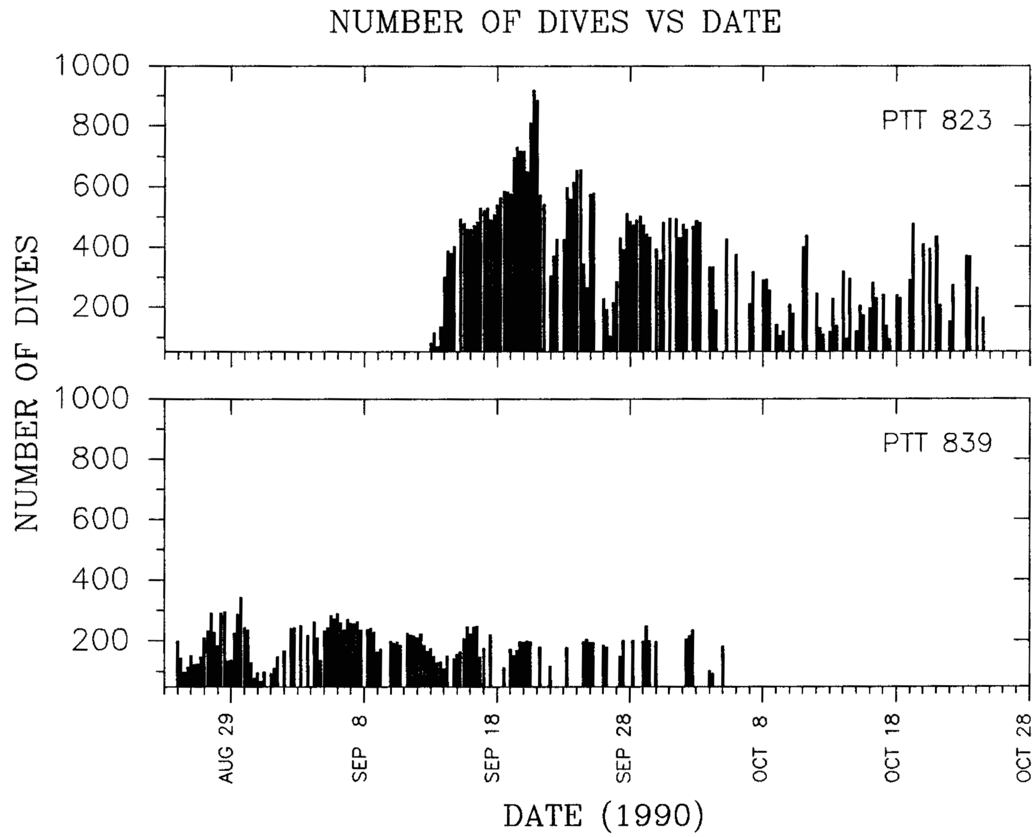


Figure 51. Chronological comparison of number of dives for PTT #823 and #839 tagged in 1990. Bars represent the number of dives during a 6-hour summary period.

Dive Duration

In both 1989 and 1990, two types of dive durations were measured: discrete dives and averages during summary periods. Discrete dive information was collected on 1770 dives plus an additional 914 submergences counted between transmissions. Due to time constraints, we did not analyze discrete dives for the 1990 whales in detail.

Discrete Data

In 1989, PTT #843 reported 304 discrete dive durations with a range of 6 to 848 s (0.1 - 14.1 min.). After considering surfacings between transmissions, the overall average was 73.5 s. The skewed distribution of discrete dive durations was typical of other species studied in detail to date (Gray whales: Harvey and Mate, 1984; Bowheads: Wursig, et al., 1984; and Humpbacks: Dolphin, 1987), where most dives were less than 30 seconds (Figure 52). Because discrete dives proved to be a subsample reflecting the summary data (see below), we concentrated our 1990 analyses on zero duration dives (see "Surface resting").

In 1990, the three longest maximum duration dives from the 1990 discrete information were 40.07, 28.23 and 17.47 minutes. All were for PTT #839. We believe the 17.47 min. (1049 s) dive is feasible but are skeptical of the two longer dives. It may have been possible for the whale to breathe in a spy-hop position without the PTT surfacing to result in such long dives. It is also possible that these were transmission errors, in which case they would not have adversely affected the average dive duration calculated for the summary period.

Summary Data

1989

The mean dive duration of PTT #843 for 4-hour periods was 74 s $\pm$ 18, lower than for all 1990 whales except PTT #823 (the male). Figure 53 shows the frequency distribution of average dive durations for all 4-hour summary periods in 1989.

1990

Average dive durations for the 6-hour summary periods are shown in Tables 11 and 12 and are presented graphically in Figure 54. The overall average dive duration for all animals in all periods was 86 s $\pm$ 48 with less than a 10% difference between periods when the data for all animals were pooled. There was considerable variation between animals (with a range of 54 s - 162 s) and between periods for individual animals. There was only a 10% difference between period averages for "Wart" (PTT #839) with a range of 95 s - 105 s compared to 90% for another female, "Stripe" (PTT #840) with a range of 113 s - 212 s. Of the seven animals analyzed, four showed their longest average dive duration between

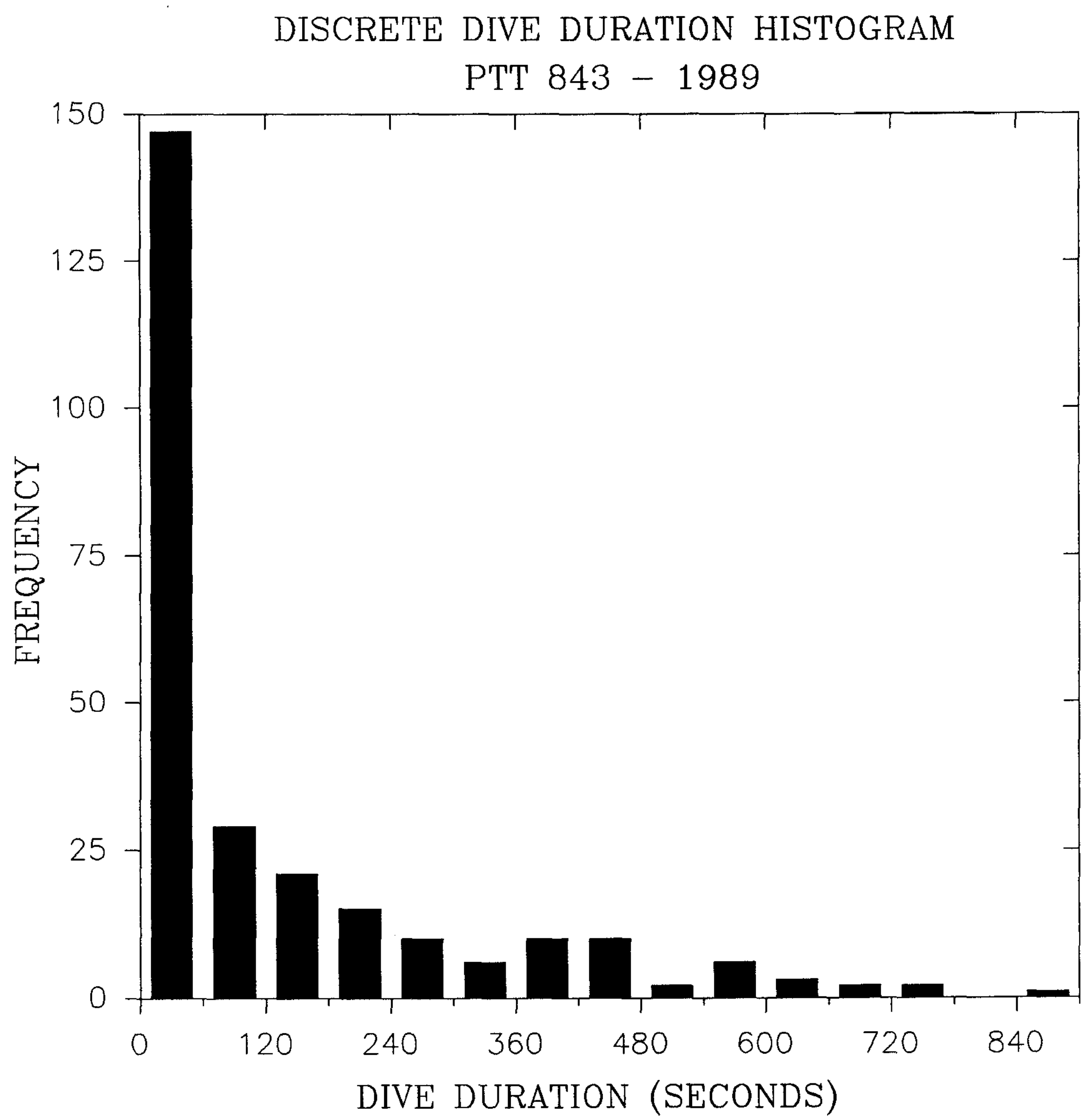


Figure 52. Frequency distribution of discrete dive durations ($\bar{x}$ = 73.5 $\pm$ 18 s) for PTT #843 (1989). Intertransmission dives (ITDs) are, by definition, less than 40 seconds and were included in the analysis (see Appendix B).

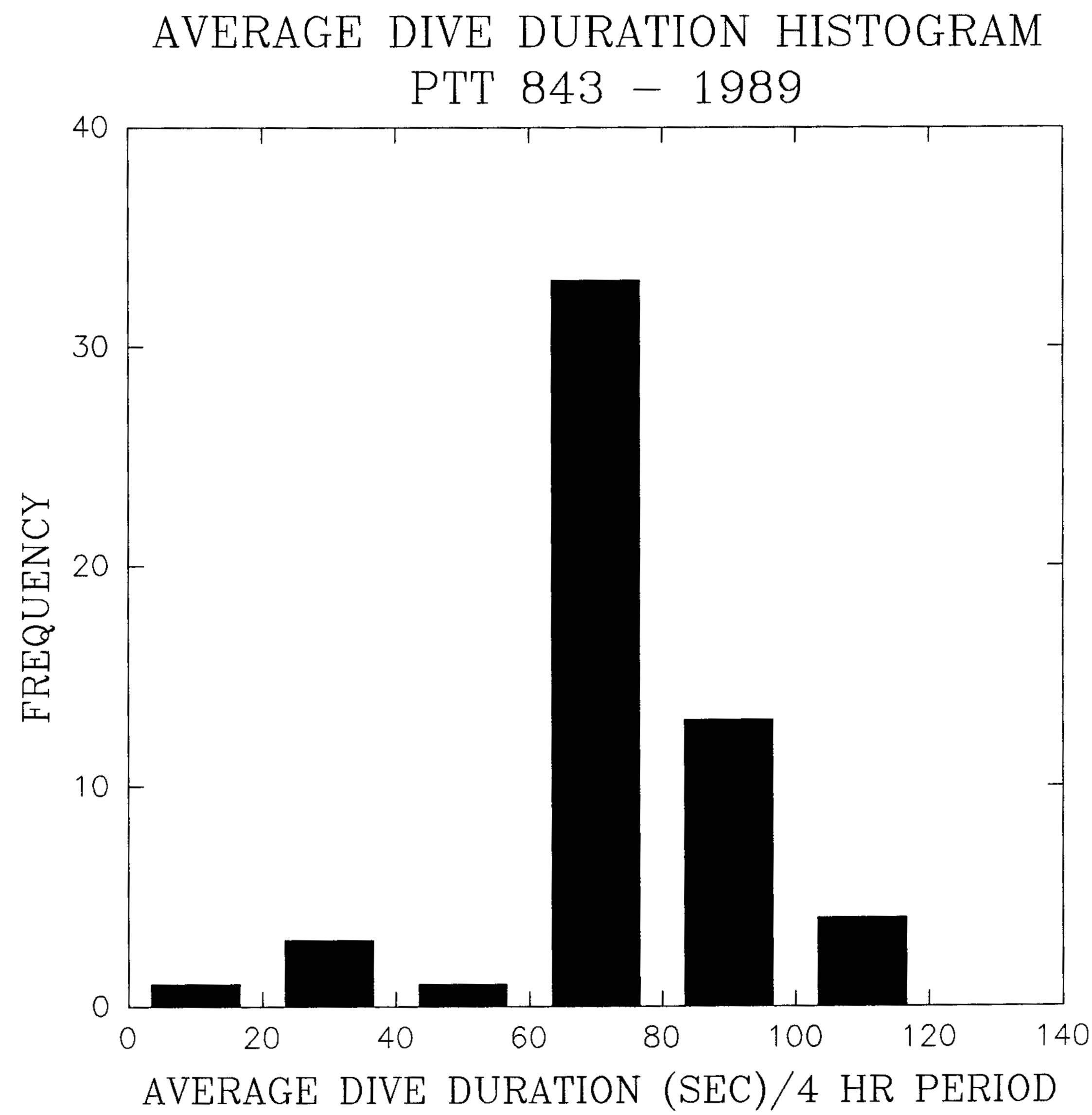


Figure 53. Frequency histogram of average dive duration during 4-hour summaries for PTT #843 tagged in 1989.

Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
avdur ave	0	86	54	100	150	83	109	100	162
avdur count	0	299	124	7	5	7	27	114	15
avdur maximum	0	342	244	160	166	102	342	198	274
avdur minimum	0	14	14	48	128	40	60	56	42
avdur stdev	0	48	36	33	13	20	59	27	69
avdur ave	1	82	53	97	142	75	114	105	113
avdur count	1	87	39	3	1	3	7	30	4
avdur maximum	1	268	232	160	142	94	268	188	154
avdur minimum	1	14	14	48	142	40	60	70	66
avdur stdev	1	44	35	46	0	24	64	26	35
avdur ave	2	89	54	128	128	102	133	102	212
avdur count	2	88	39	1	1	1	9	33	4
avdur maximum	2	342	168	128	128	102	342	198	274
avdur minimum	2	16	16	128	128	102	84	60	152
avdur stdev	2	54	31	0	0	0	76	29	45
avdur ave	3	88	62	93	160	100	89	98	182
avdur count	3	74	31	3	2	1	5	28	4
avdur maximum	3	264	244	104	166	100	110	178	264
avdur minimum	3	16	16	88	154	100	60	58	102
avdur stdev	3	48	45	7	6	0	19	27	58
avdur ave	4	81	43	-0-	160	77	82	95	134
avdur count	4	50	15	0	1	2	6	23	3
avdur maximum	4	246	118	-0-	160	86	100	156	246
avdur minimum	4	16	16	-0-	160	68	70	56	42
avdur stdev	4	41	23	-0-	0	9	11	24	84

Table 11. Average dive duration summarized by period for whales tagged in 1990. [Ave = average dive duration for the designated period; count = # of summary periods from which statistics were computed; maximum/minimum = maximum/minimum average duration of dives calculated during the summary period designated; stdev = standard deviation of the average; period 0 = all periods combined; PTTALL = all PTTs combined.]

Data from summary table for RW90
Errors removed

		PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
avdur	ave	0	86	54	100	150	83	109	100	162
avdur	ave	1	82	53	97	142	75	114	105	113
avdur	ave	2	89	54	128	128	102	133	102	212
avdur	ave	3	88	62	93	160	100	89	98	182
avdur	ave	4	81	43	-0-	160	77	82	95	134
avdur	count	0	299	124	7	5	7	27	114	15
avdur	count	1	87	39	3	1	3	7	30	4
avdur	count	2	88	39	1	1	1	9	33	4
avdur	count	3	74	31	3	2	1	5	28	4
avdur	count	4	50	15	0	1	2	6	23	3
avdur	maximum	0	342	244	160	166	102	342	198	274
avdur	maximum	1	268	232	160	142	94	268	188	154
avdur	maximum	2	342	168	128	128	102	342	198	274
avdur	maximum	3	264	244	104	166	100	110	178	264
avdur	maximum	4	246	118	-0-	160	86	100	156	246
avdur	minimum	0	14	14	48	128	40	60	56	42
avdur	minimum	1	14	14	48	142	40	60	70	66
avdur	minimum	2	16	16	128	128	102	84	60	152
avdur	minimum	3	16	16	88	154	100	60	58	102
avdur	minimum	4	16	16	-0-	160	68	70	56	42
avdur	stdev	0	48	36	33	13	20	59	27	69
avdur	stdev	1	44	35	46	0	24	64	26	35
avdur	stdev	2	54	31	0	0	0	76	29	45
avdur	stdev	3	48	45	7	6	0	19	27	58
avdur	stdev	4	41	23	-0-	0	9	11	24	84

Table 12. Average dive duration summarized by statistic category and PTT. See note on Table 11.

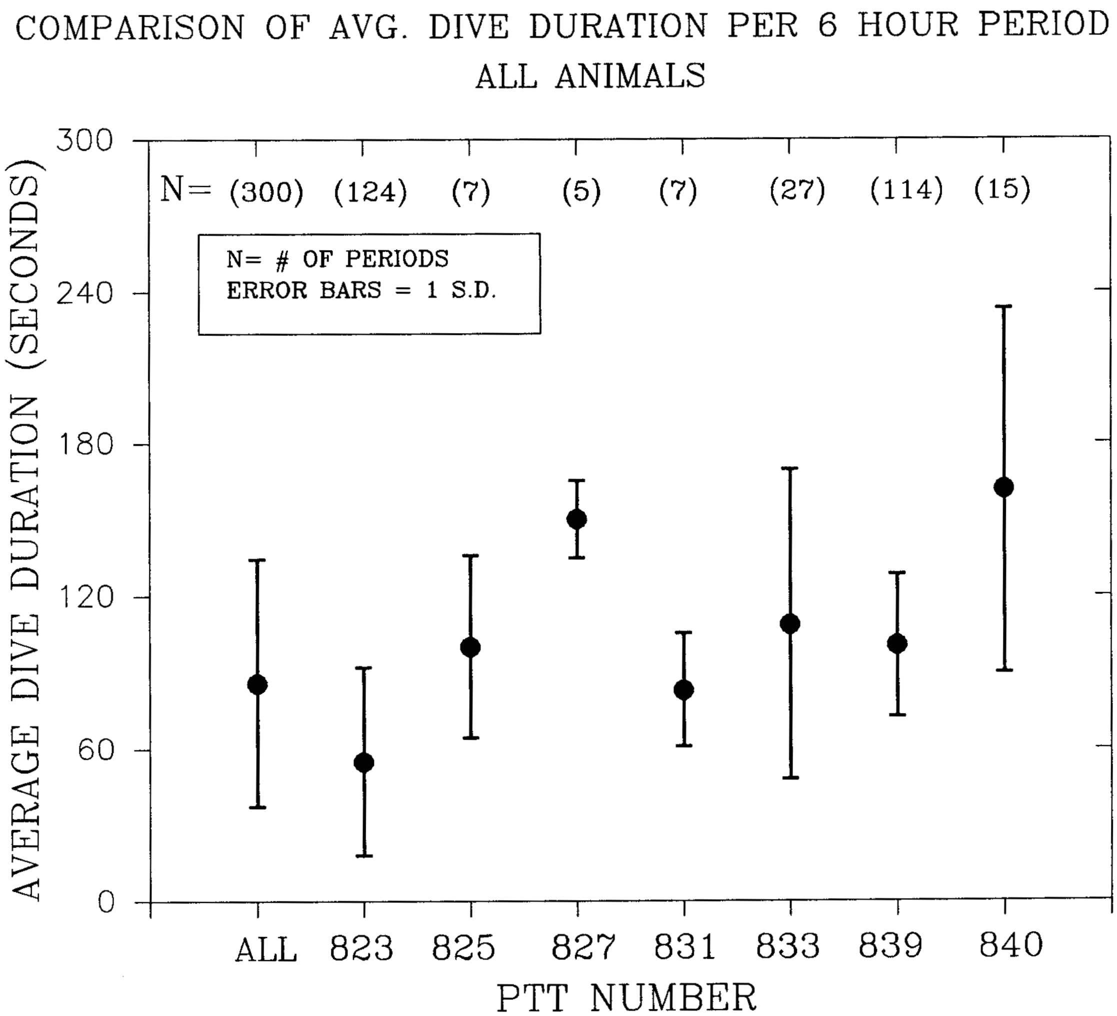


Figure 54. Comparison of average dive durations (seconds) during 6-hour summary periods for whales tagged in 1990.

midnight and sunrise (Period 2). Four whales had their shortest average dive from dusk to midnight (Period 1). The longest (maximum) overall average dive duration for individual animals varied from 102 s (PTT #831) to 342 s (PTT #833).

A frequency histogram of average dive duration for all animals is shown in Figure 55. Figures 56 - 62 demonstrate the distribution of average dive duration for the individual animals. PTT #823 (Figure 56) and PTT #839 (Figure 61) represent 80% of the 299 samples for all PTTs. PTT #823's overall average dive duration was approximately half that for PTT #839 (54 s versus 100 s). Recall that the number of dives in a six hour period for PTT #823 was precisely double that for PTT #839, affirming the reciprocal relationship of these two characteristics.

There were dramatic differences in diving strategies. "Willie"(PTT #823) had shorter minimum average dive durations and less variation for all periods (14 s - 16 s) than any other whale. These short average dive durations occurred in extremely warm water at the southern extent of the whale's track. At the other extreme, "Stripe's" (PTT #840) lowest average varied by 362% between periods from 42 s - 152 s. PTT #840 emphasized longer dives with the highest overall average of 162 s. This was the pregnant female and also the fastest moving animal. PTT #833, a juvenile which did not range far from its tagging site, had the highest maximum average dive duration (342 s) for one period.

Figures 63 and 64 show the relationship of average dive duration to calendar date. For two of these seven animals (PTT #823 and PTT #833), the largest number of dives in a 6-hour period occurred during the first day after tagging. While this could be a reaction to tagging, it was not observed in other animals. The data show no obvious correlation with weather.

Dive durations are useful in examining diving capability, foraging strategies, behavioral differences, possible harassment and estimating sighting factors for aerial and boat surveys. The numbers reported here represent longer average dives ($\bar{x}$ = 86 s) than those reported during Cetacean and Turtle Assessment Program (CeTAP) studies ($\bar{x}$ = 52 s) conducted by ship (CeTAP, 1982). We cannot explain this difference with assurance, however, it may be due to individual variations, area, time of year, behavior or methodology. There may be some inadvertent harassment affect from the ship which must stay within reception range during VHF monitoring. The difference is not attributable to the definition of dives. If we had adjusted our definition of a dive to that used by CeTAP, the differences in average dive duration would have been even larger.

Long dive durations suggest that aerial and ship surveys at high speed may miss many whales while they are submerged. For bowhead whales, another species in the right whale family, Wursig, et al. (1984) observed dives averaging 47 s in 1980 and 1981, but 86 s in 1982 when there was less socialization. Wartzok, et al. (1990) found that dives of radio-tagged bowheads averaged 50 s overall and 40 s when socializing.

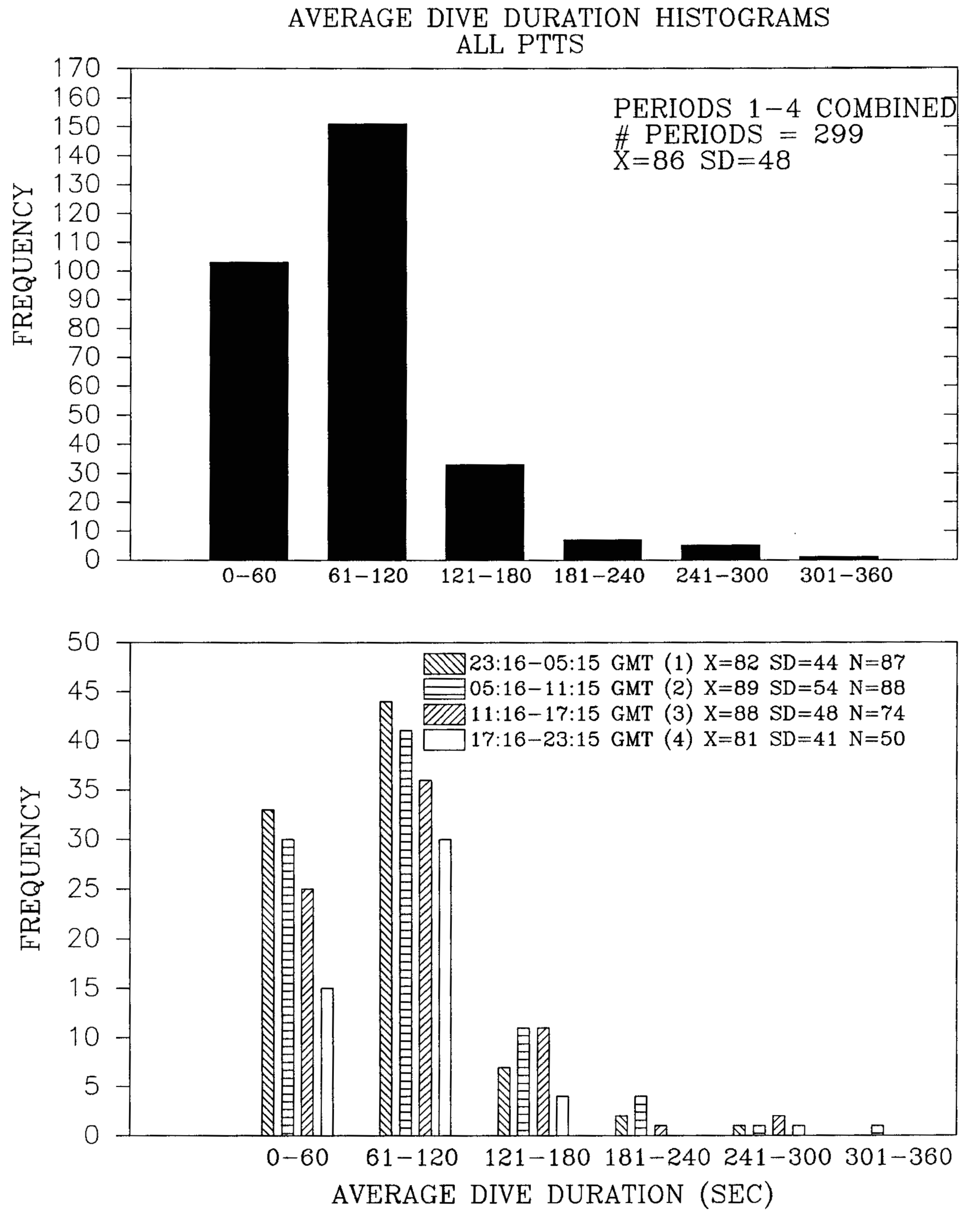


Figure 55. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for all 1990 PTTs (#823, #825, #827, #831, #833, #839 and #840). Note: x = mean average dive duration during the designated period; sd = standard deviation of the mean; N = # of summary periods from which the histogram was generated.

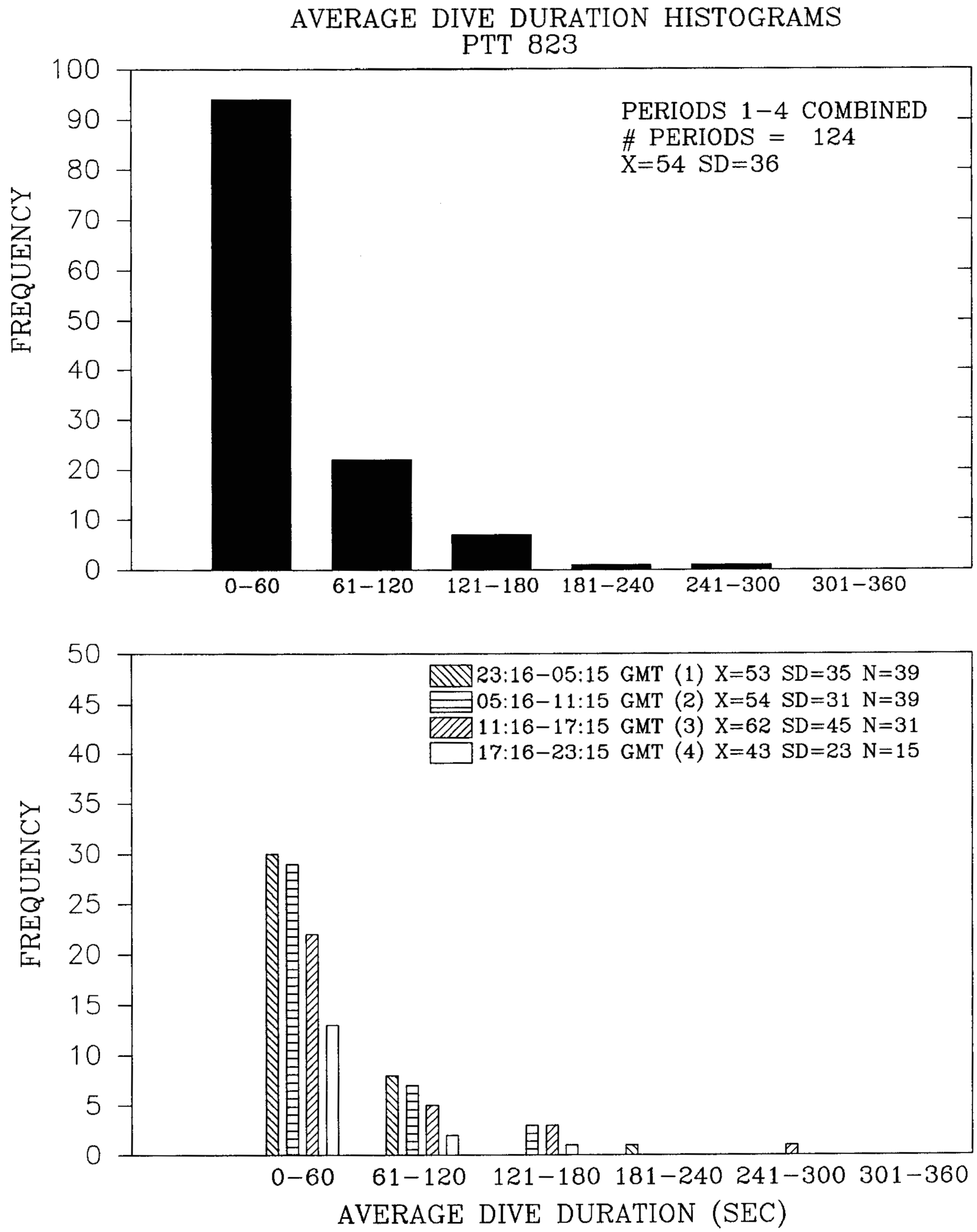


Figure 56. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #823. See note in Figure 55.

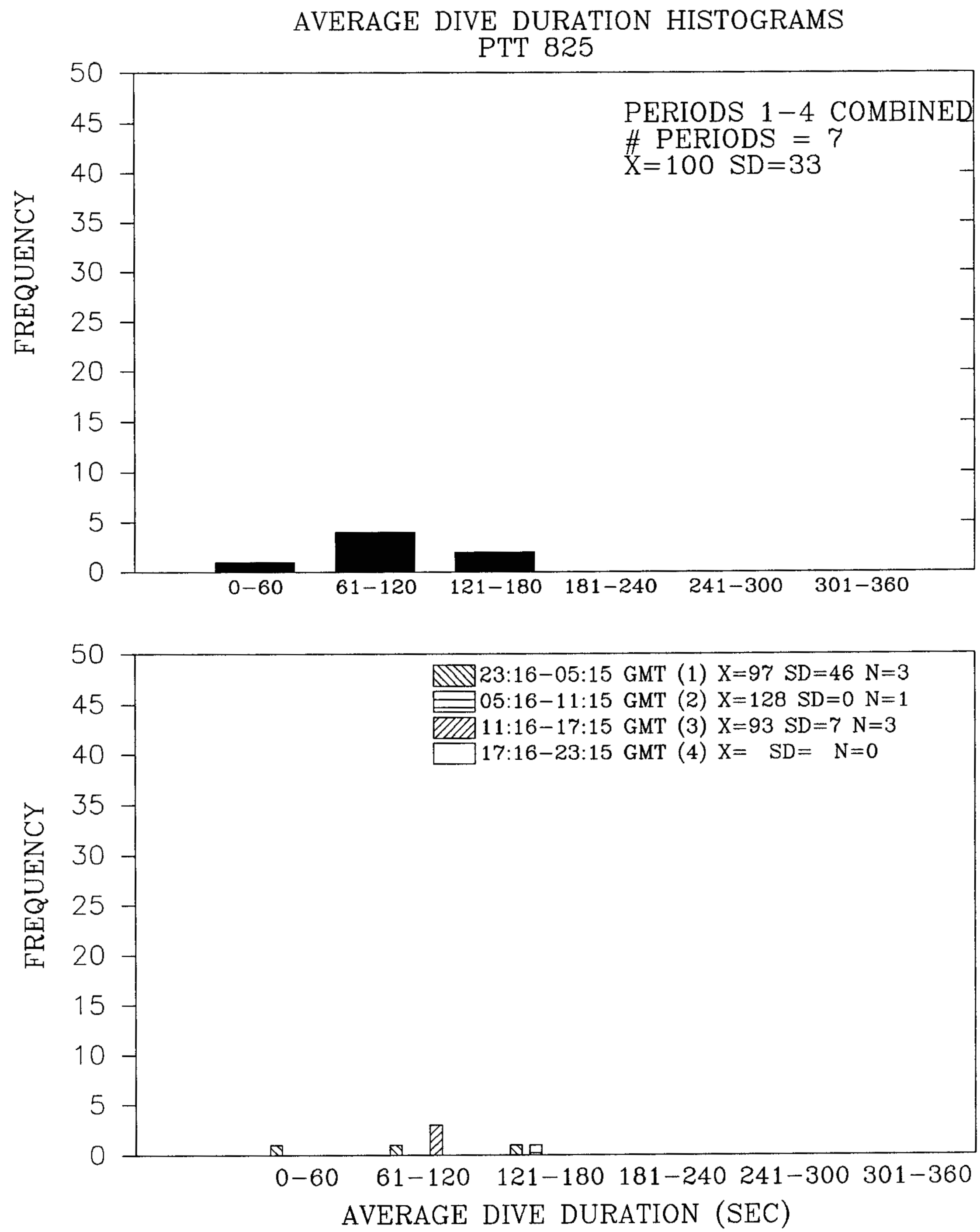


Figure 57. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #825. See note in Figure 55.

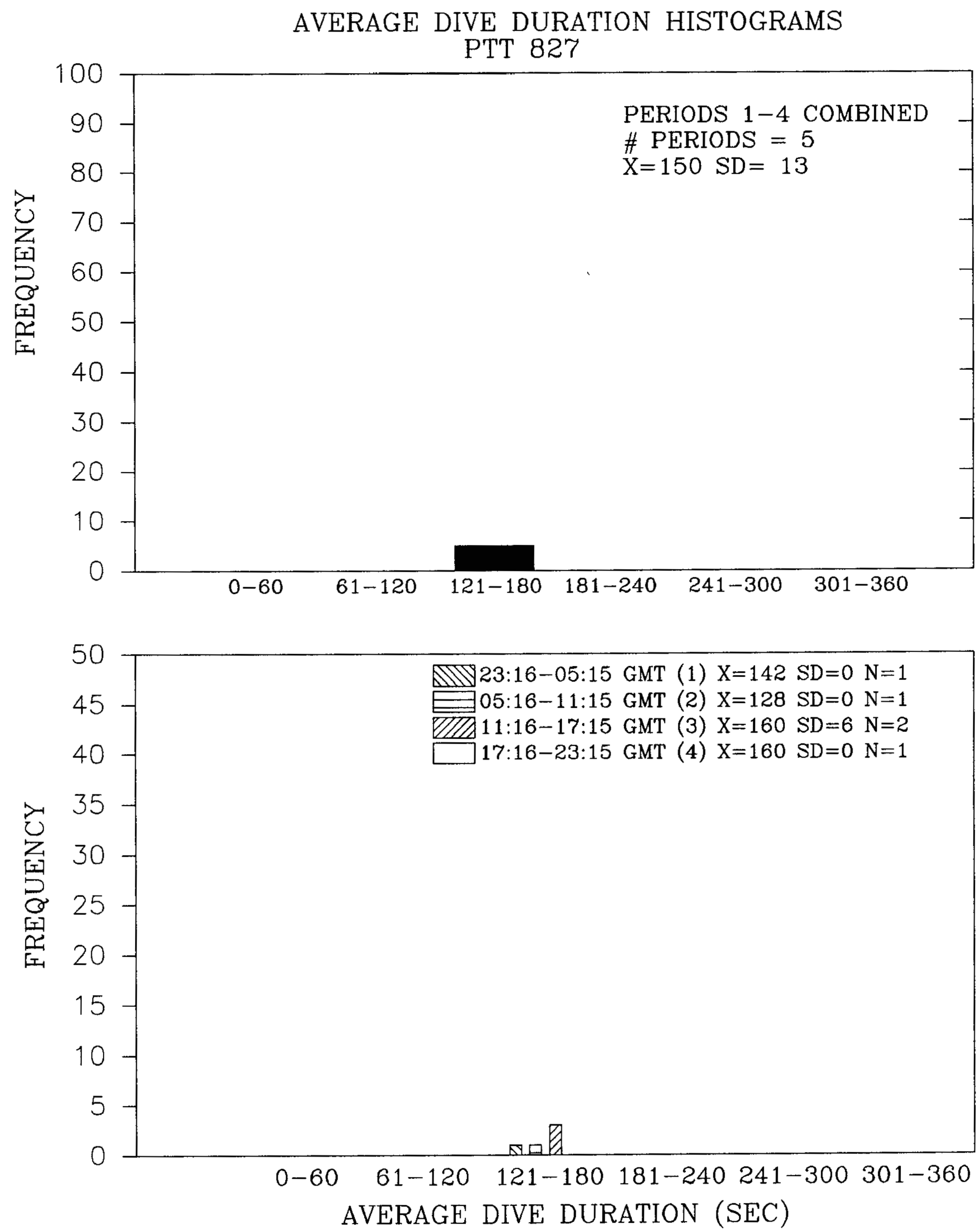


Figure 58. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #827. See note in Figure 55.

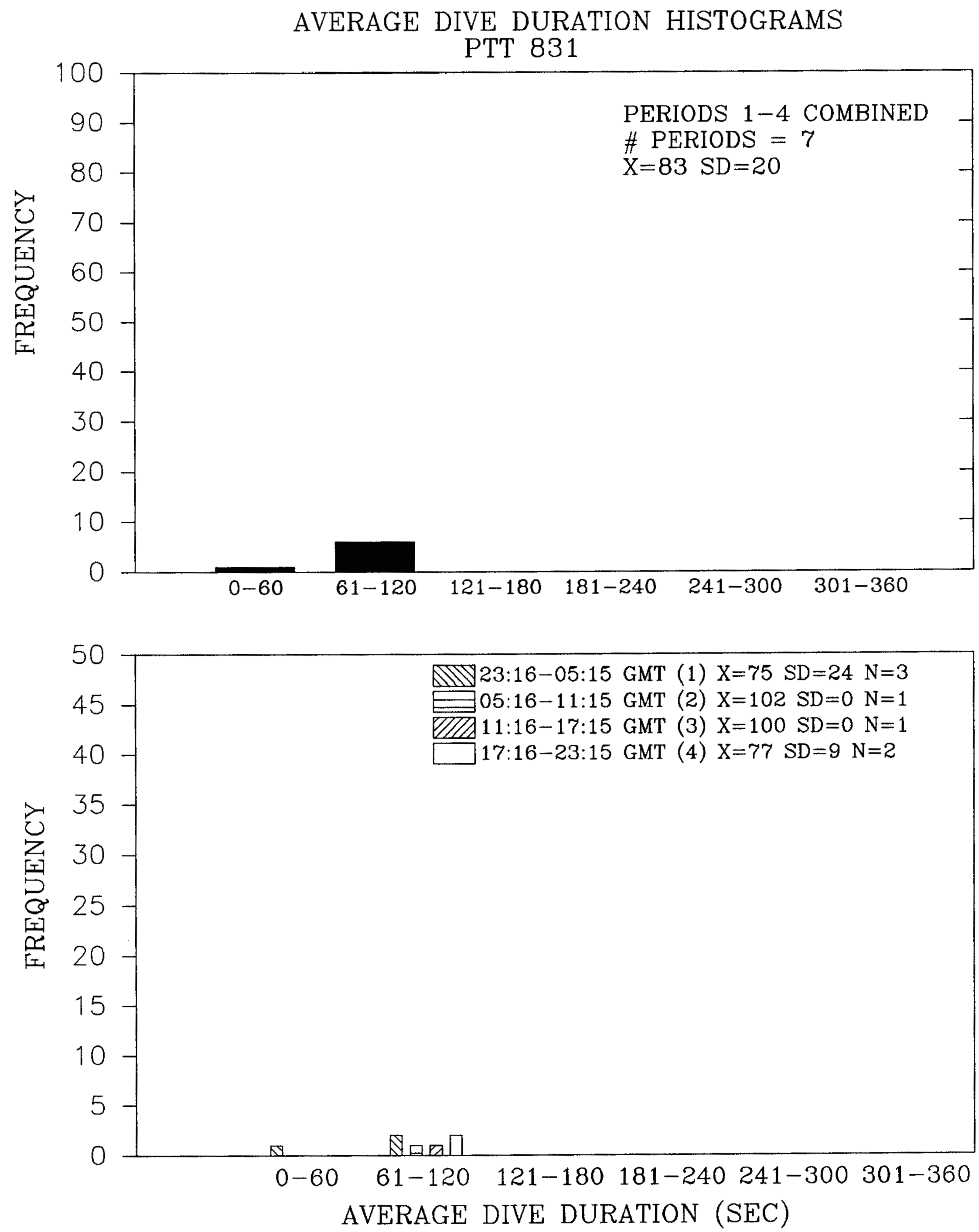


Figure 59. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #831. See note in Figure 55.

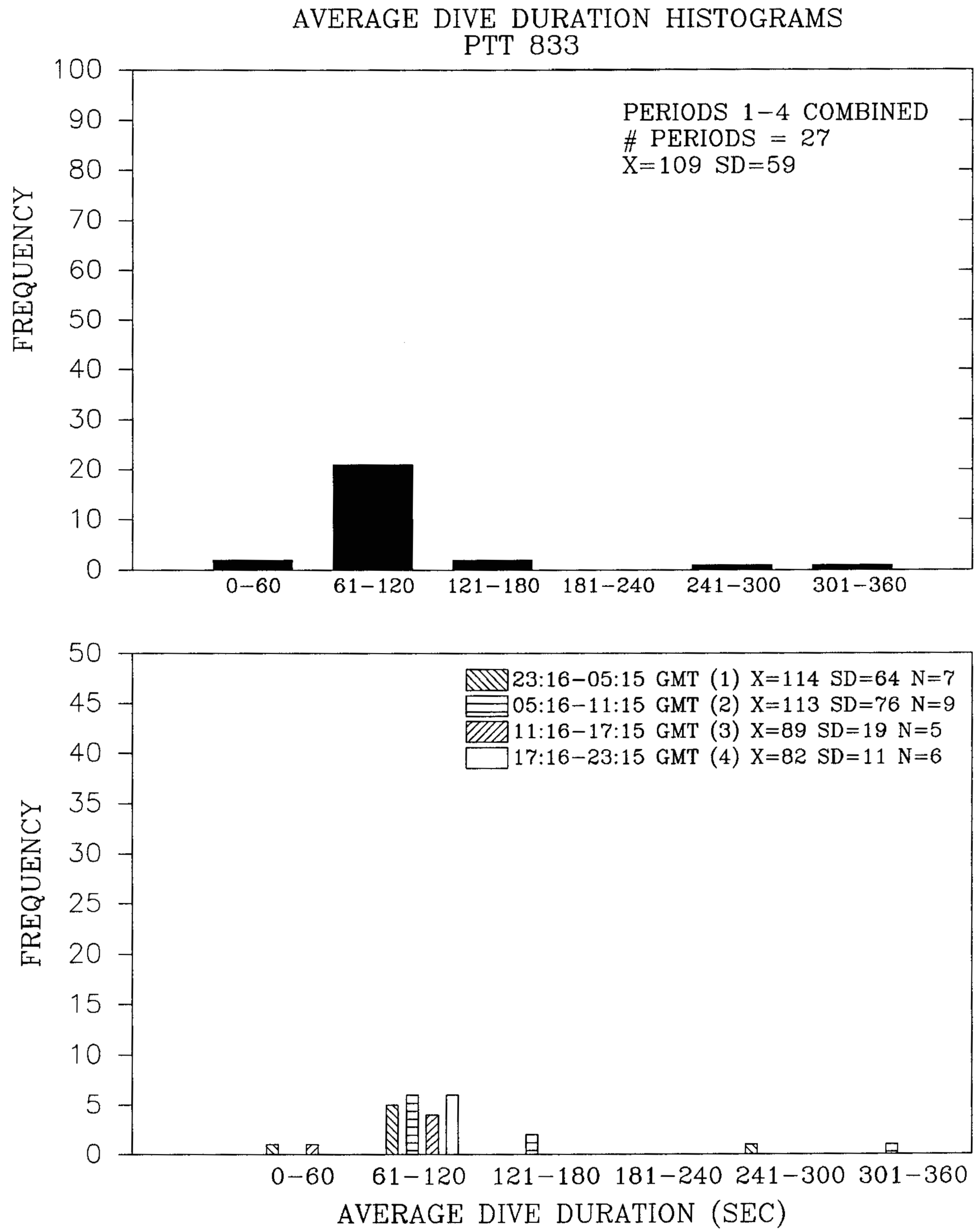


Figure 60. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #833. See note in Figure 55.

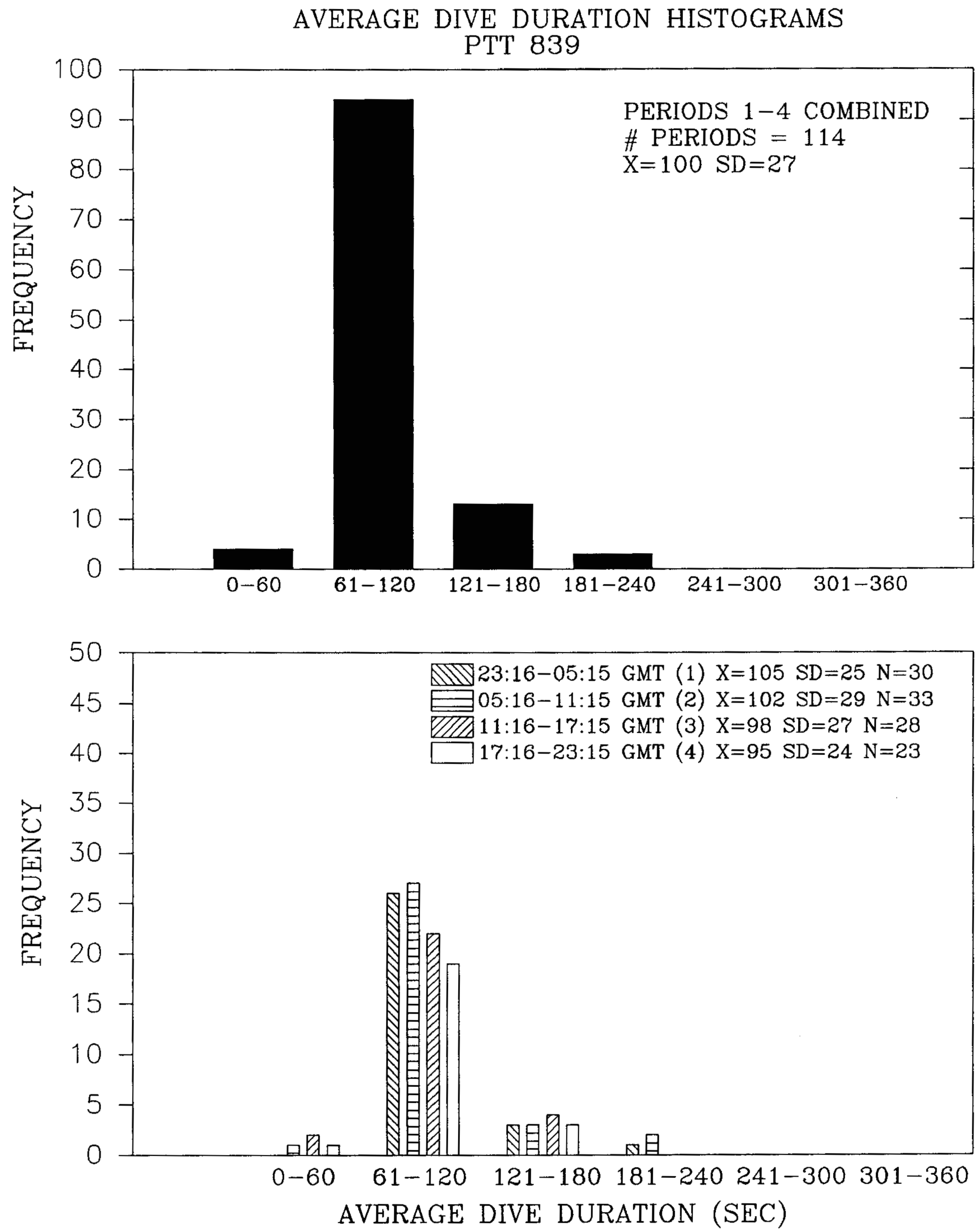


Figure 61. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #839. See note in Figure 55.

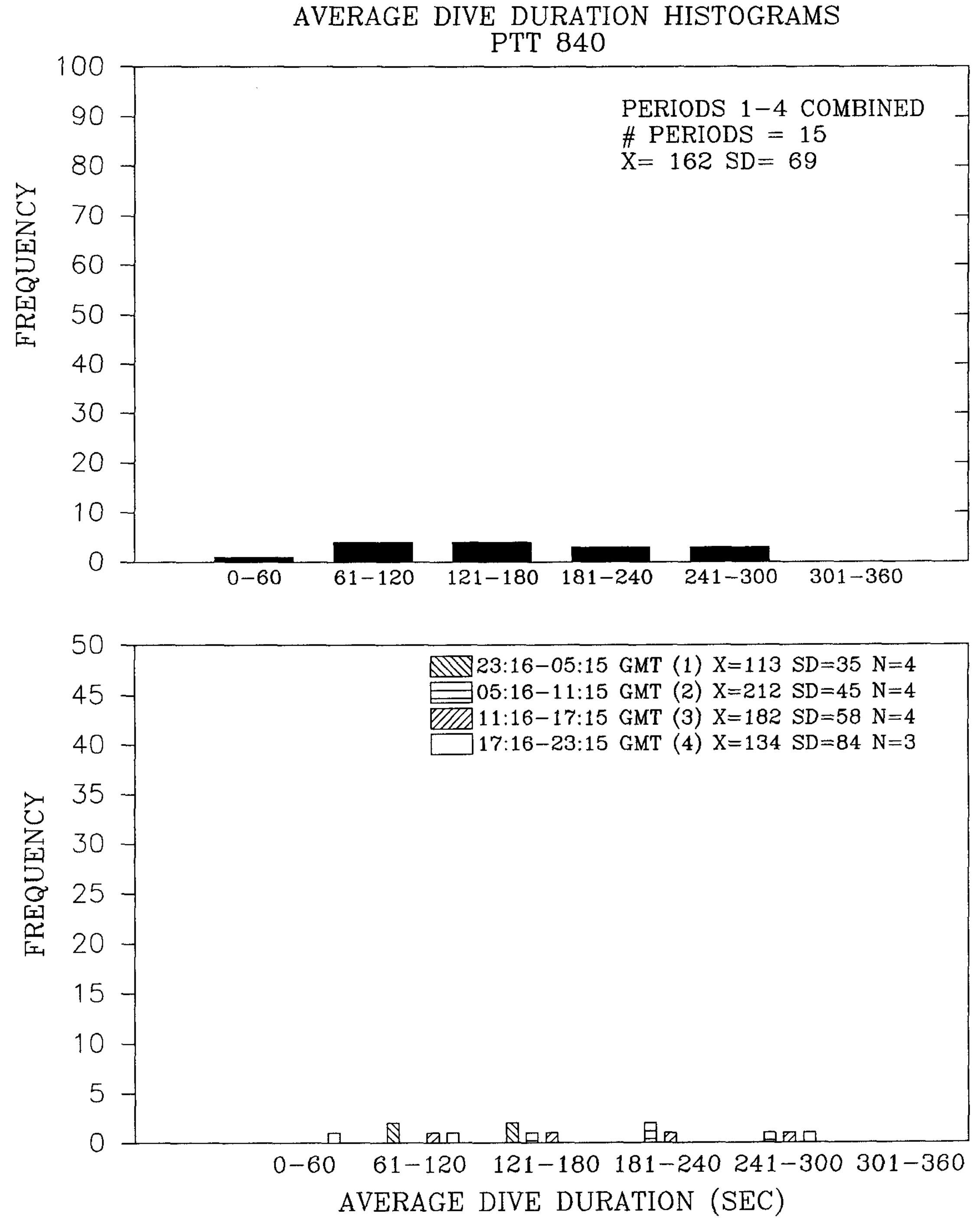


Figure 62. Frequency histogram of average dive duration (seconds) during all 6-hour summary periods for PTT #840. See note in Figure 55.

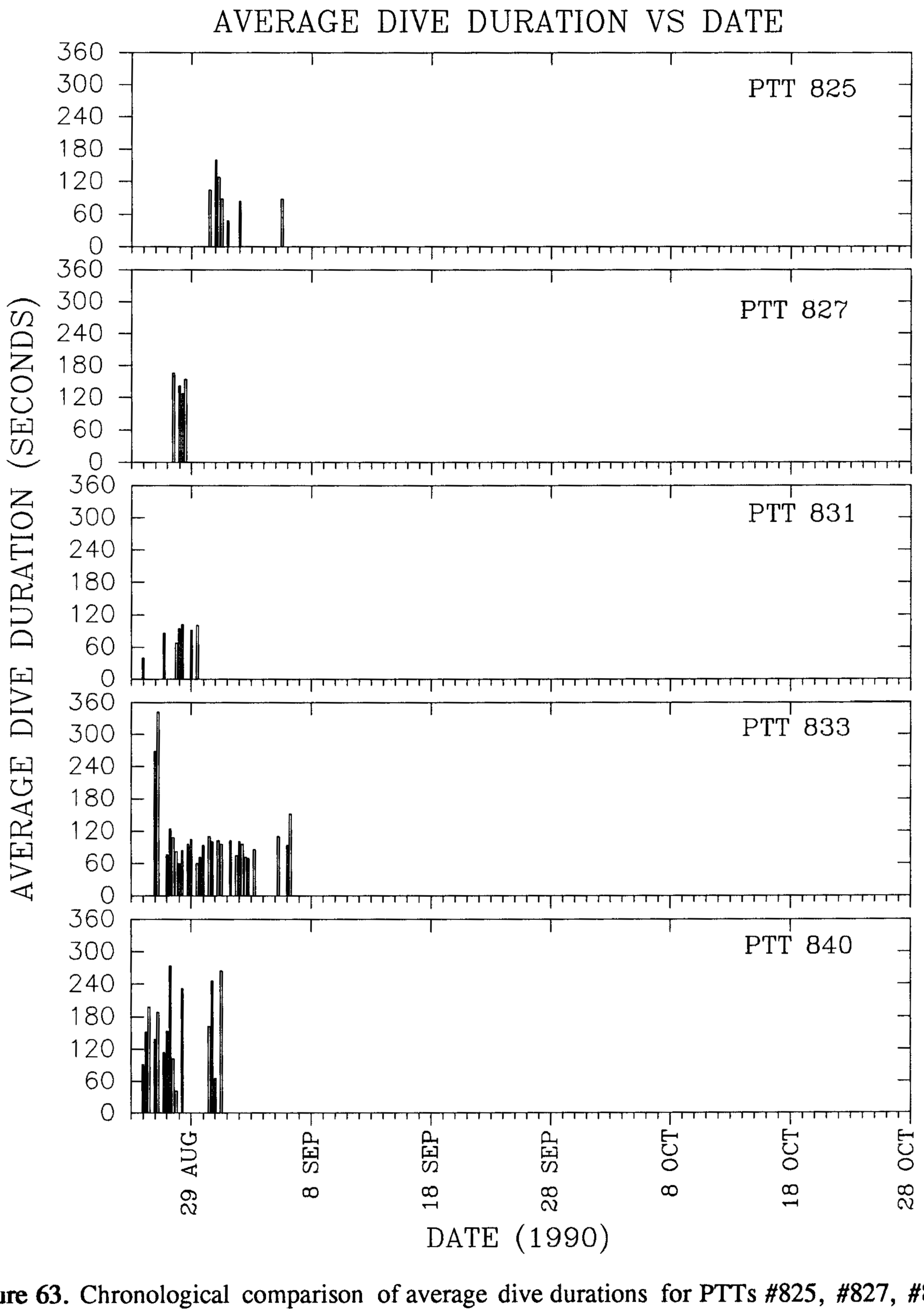


Figure 63. Chronological comparison of average dive durations for PTTs #825, #827, #831, #833 and #840 tagged in 1990. Bars represent average dive durations for 6-hour summary periods.

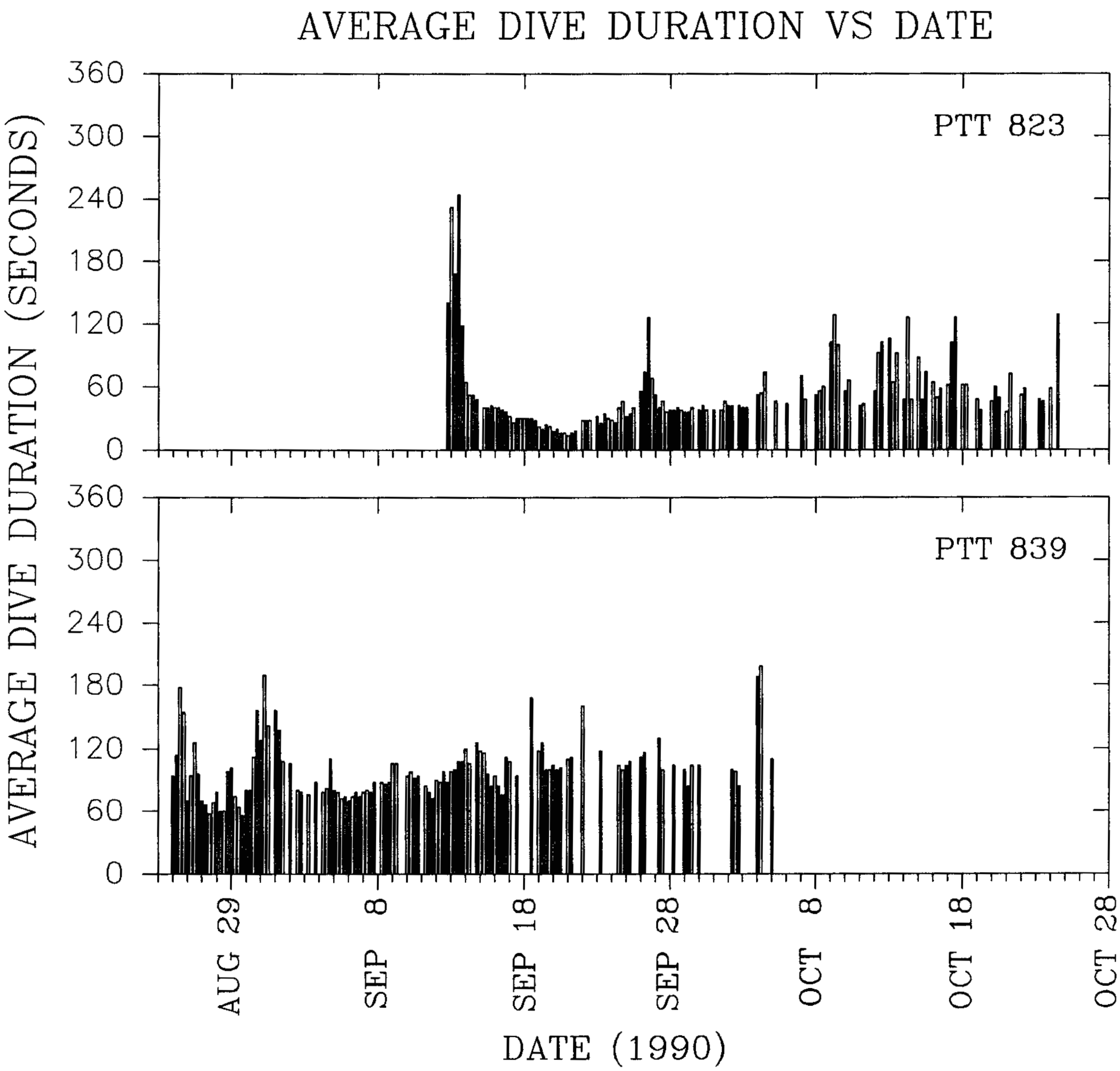


Figure 64. Chronological comparison of the average dive durations for PTTs #823 and #839 tagged in 1990. Bars represent average dive durations during 6-hour summary periods.

Submergence Time

Using summary data, the average dive duration was multiplied by the number of dives in each period to obtain the time (seconds) spent submerged during a summary period (average duration x number of dives = TSUB). This is expressed as a percentage of the entire summary period (21,600 s) in 1990 and 14,400 in 1989.

1989

Figure 65 shows the chronological progression of percentage time submerged and locations of PTT #843. The time spent submerged was more consistent in the Bay of Fundy and on Brown's Bank than during the transit into the Gulf of Maine and around Jeffrey's Ledge, when some summary periods suggest significant periods at the surface (low % TSUB).

Figure 66 shows the average percent time submerged by time of day (in GMT). This figure shows some variation throughout the day. The largest sample occurred in the early afternoon from 1600 - 2000 GMT (1200 - 1600 EST; see Figure 6 for relationships of GMT, EST and daily light cycle) and has the highest percentage of time submerged and least standard deviation. This is a time field biologists often refer to as the "mid-day lull" when whales are less frequently observed. This may be explained in part by the high TSUB values for that time of day.

1990

A total of 294 calculations for time submerged are summarized in Tables 13 and 14. The seven whales spent a combined average of 78% (range: 86% - 97%) of their time submerged, while individuals spent an average of 67% (PTT #840) to 87% (PTT #827) of their time submerged. Individual whales were reasonably consistent. Six whales had differences between their high and low period averages of 4% - 12%. The mean for each animal is depicted (with standard deviation) in Figure 67. There are significant differences between individual animals. A frequency histogram of the percent time submerged for all 1990 whales combined is shown in Figure 68 with details on individual whales shown in Figures 69 - 75. Animals most commonly spent 86% - 90% of their 6-hour summary periods submerged. For four of the 1990 whales, the highest average percentage of time spent submerged occurred between dawn and noon (Period 3), compared to noon to 1800 local time for PTT #843 in 1989. The lowest average time submerged occurred for three whales between dusk and midnight (Period 1) and another three whales between midnight to sunrise (Period 2). PTT #825, PTT #827 and PTT #840 had the same periods for their high and low averages, although all had low sample sizes. "Wart" and "Willie" (PTT #823 and PTT #839) had large sample sizes, had different periods for their high and low average TSUB, and also differed from all other whales.

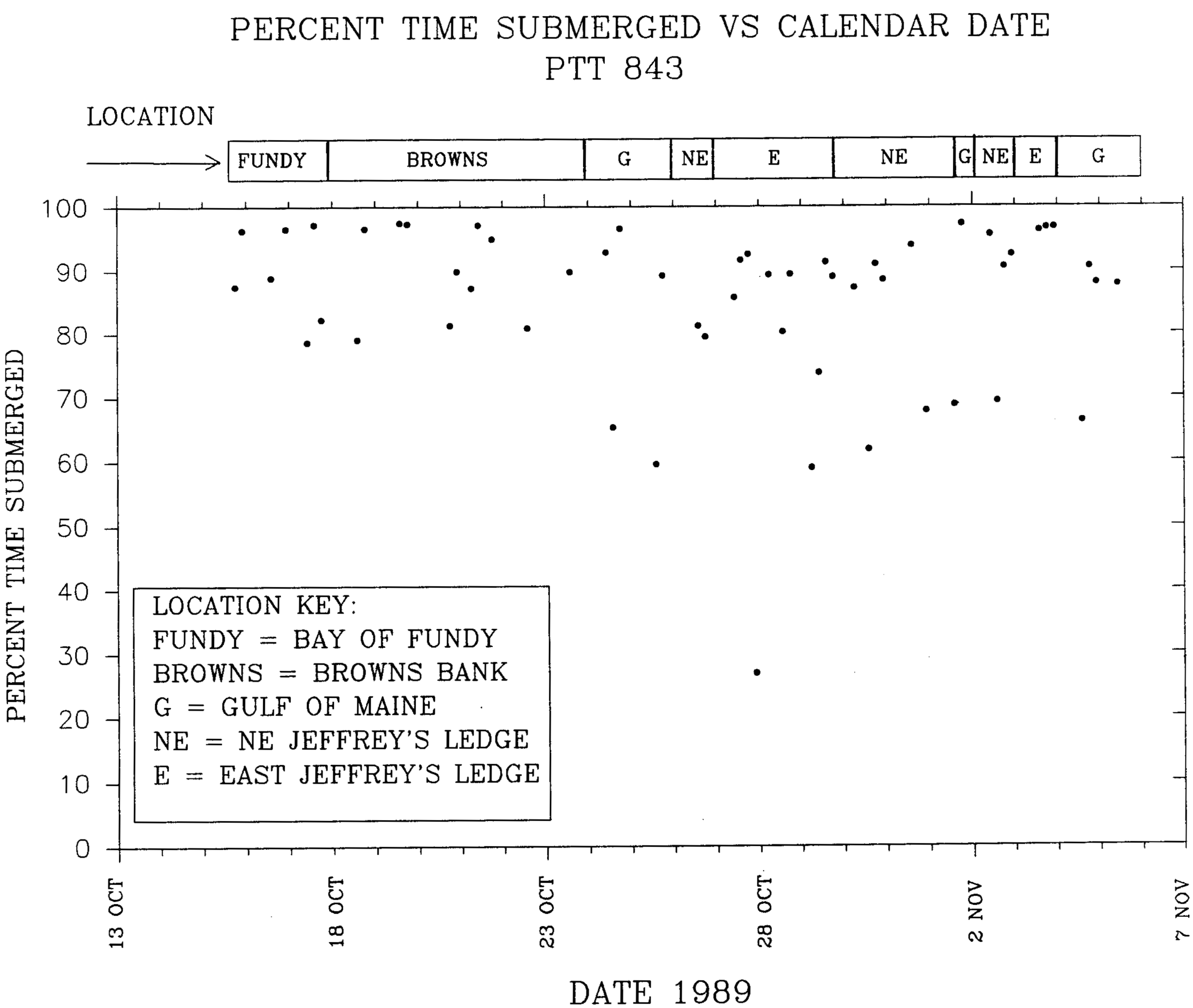


Figure 65. The percent time submerged (during a 4-hour summary period) versus calendar date and area for PTT #843 tagged in 1989.

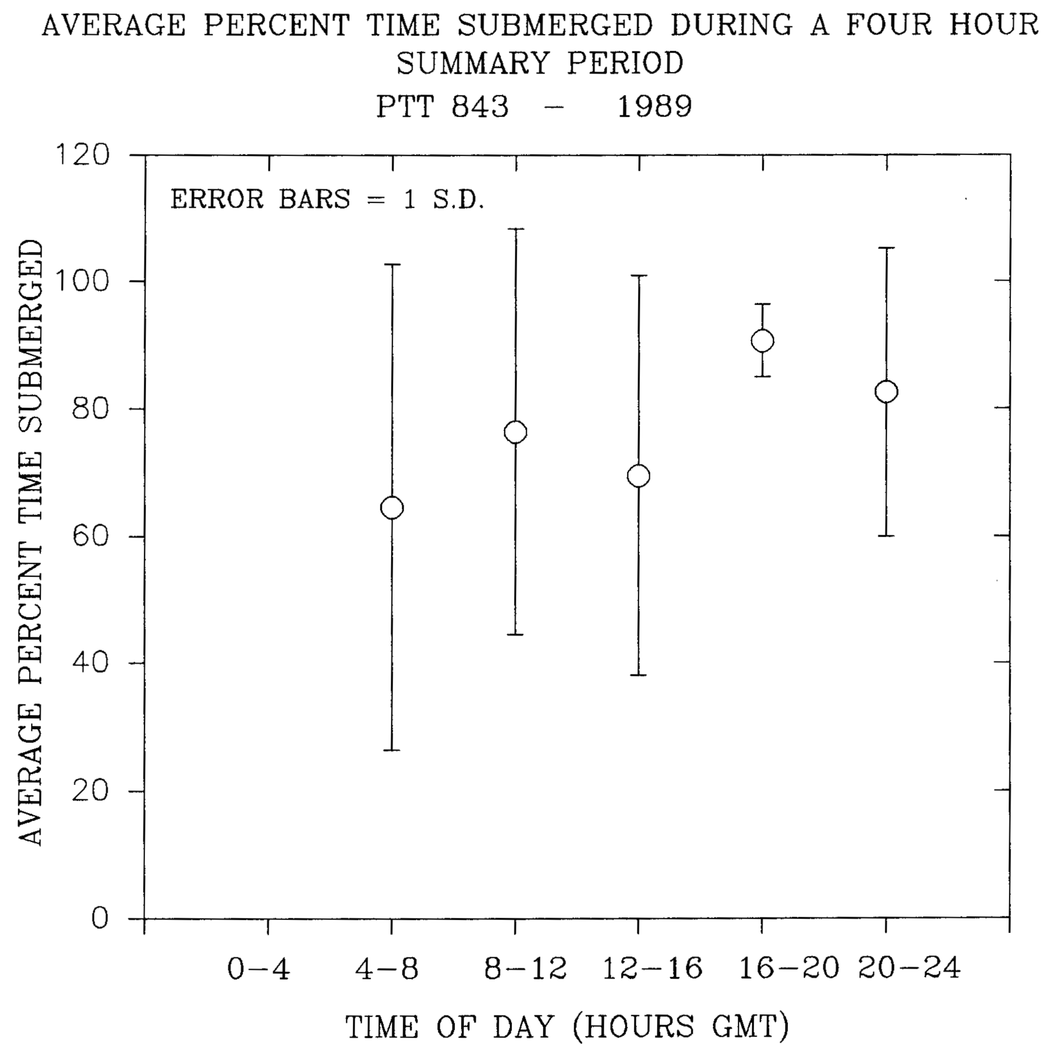


Figure 66. A comparison of the average percent time submerged between 4-hour summary periods for PTT #843.

Data from summary table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
%tsub ave	0	78	72	86	87	86	81	83	67
%tsub count	0	294	122	7	5	6	26	113	15
%tsub maximum	0	97	97	95	91	96	92	97	77
%tsub minimum	0	36	36	80	81	45	45	49	52
%tsub stdev	0	13	13	5	3	18	10	11	7
%tsub ave	1	75	70	86	85	70	76	82	63
%tsub count	1	85	39	3	1	2	7	29	4
%tsub maximum	1	97	92	91	85	94	90	97	71
%tsub minimum	1	36	36	80	85	45	45	49	52
%tsub stdev	1	14	13	4	0	24	15	12	7
%tsub ave	2	78	72	80	81	96	81	85	62
%tsub count	2	86	38	1	1	1	8	33	4
%tsub maximum	2	96	93	80	81	96	89	96	69
%tsub minimum	2	42	42	80	81	96	58	53	54
%tsub stdev	2	13	13	0	0	0	9	11	6
%tsub ave	3	79	72	89	89	95	86	84	74
%tsub count	3	73	30	3	2	1	5	28	4
%tsub maximum	3	97	97	95	91	95	92	97	76
%tsub minimum	3	45	45	85	87	95	82	64	71
%tsub stdev	3	12	14	4	1	0	4	9	1
%tsub ave	4	80	79	---	88	92	82	81	70
%tsub count	4	50	15	0	1	2	6	23	3
%tsub maximum	4	96	92	---	88	93	87	96	77
%tsub minimum	4	57	57	---	88	90	74	57	59
%tsub stdev	4	10	10	---	0	1	4	11	7

Table 13. Percentage of time spent submerged summarized by period for whales tagged in 1990. [Note: ave = average percentage of time spent submerged for the designated period; count = # of summary periods from which statistics were computed; maximum/minimum = maximum/minimum percent time submerged during the summary period designated; stdev = standard deviation of the average; period 0 = all periods combined; PTTALL = all PTTs combined.]

Data from summary table for RW90
Errors removed

	PERIOD	PTTALL	PTT823	PTT825	PTT827	PTT831	PTT833	PTT839	PTT840
%tsub ave	0	78	72	86	87	86	81	83	67
%tsub ave	1	75	70	86	85	70	76	82	63
%tsub ave	2	78	72	80	81	96	81	85	62
%tsub ave	3	79	72	89	89	95	86	84	74
%tsub ave	4	80	79	---	88	92	82	81	70
%tsub count	0	294	122	7	5	6	26	113	15
%tsub count	1	85	39	3	1	2	7	29	4
%tsub count	2	86	38	1	1	1	8	33	4
%tsub count	3	73	30	3	2	1	5	28	4
%tsub count	4	50	15	0	1	2	6	23	3
%tsub maximum	0	97	97	95	91	96	92	97	77
%tsub maximum	1	97	92	91	85	94	90	97	71
%tsub maximum	2	96	93	80	81	96	89	96	69
%tsub maximum	3	97	97	95	91	95	92	97	76
%tsub maximum	4	96	92	---	88	93	87	96	77
%tsub minimum	0	36	36	80	81	45	45	49	52
%tsub minimum	1	36	36	80	85	45	45	49	52
%tsub minimum	2	42	42	80	81	96	58	53	54
%tsub minimum	3	45	45	85	87	95	82	64	71
%tsub minimum	4	57	57	---	88	90	74	57	59
%tsub stdev	0	13	13	5	3	18	10	11	7
%tsub stdev	1	14	13	4	0	24	15	12	7
%tsub stdev	2	13	13	0	0	0	9	11	6
%tsub stdev	3	12	14	4	1	0	4	9	1
%tsub stdev	4	10	10	---	0	1	4	11	7

Table 14. Percentage of time spent submerged summarized by statistical category for whales tagged in 1990. See Table 13 note for details.

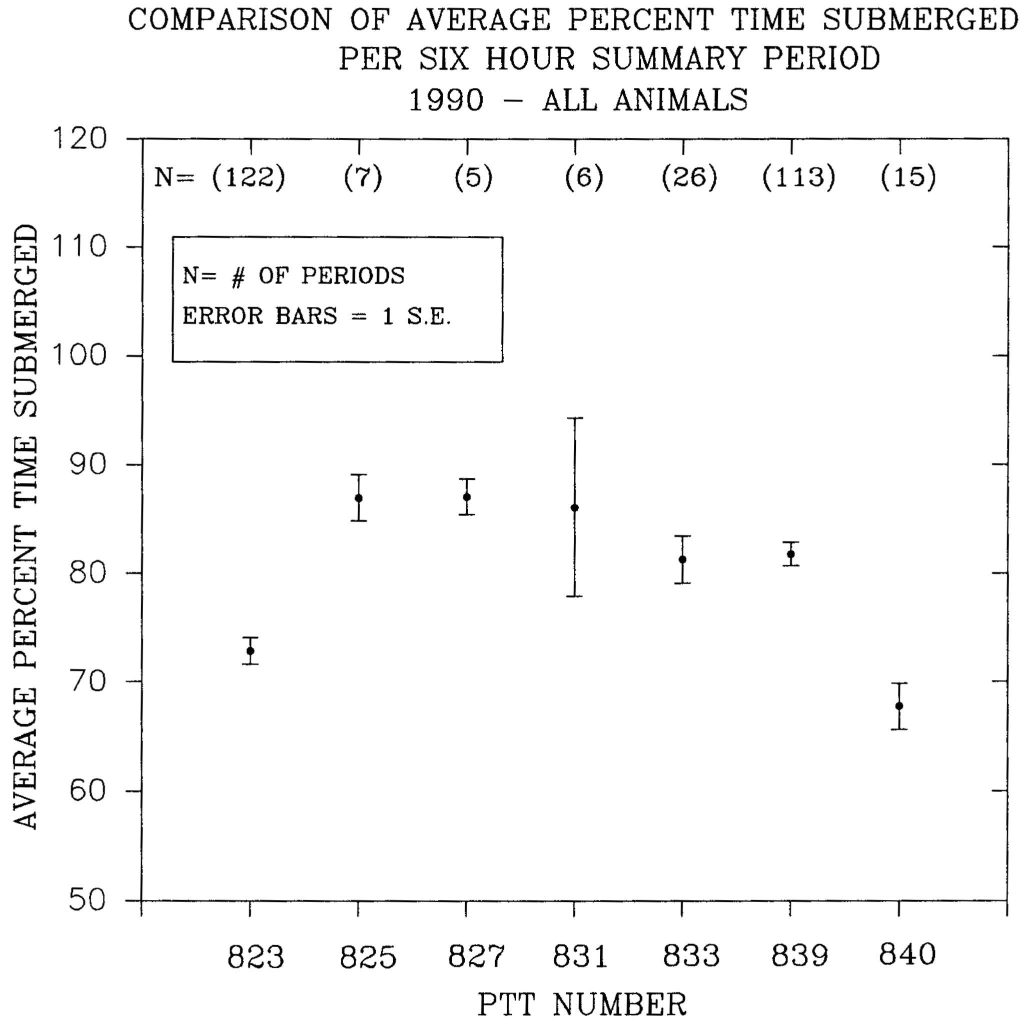


Figure 67. A comparison of the average percent time submerged between PTTs #823, #825, #827, #831, #833, #839 and #840 tagged in 1990. N = number of error-free summary periods used. Error bars = sd.

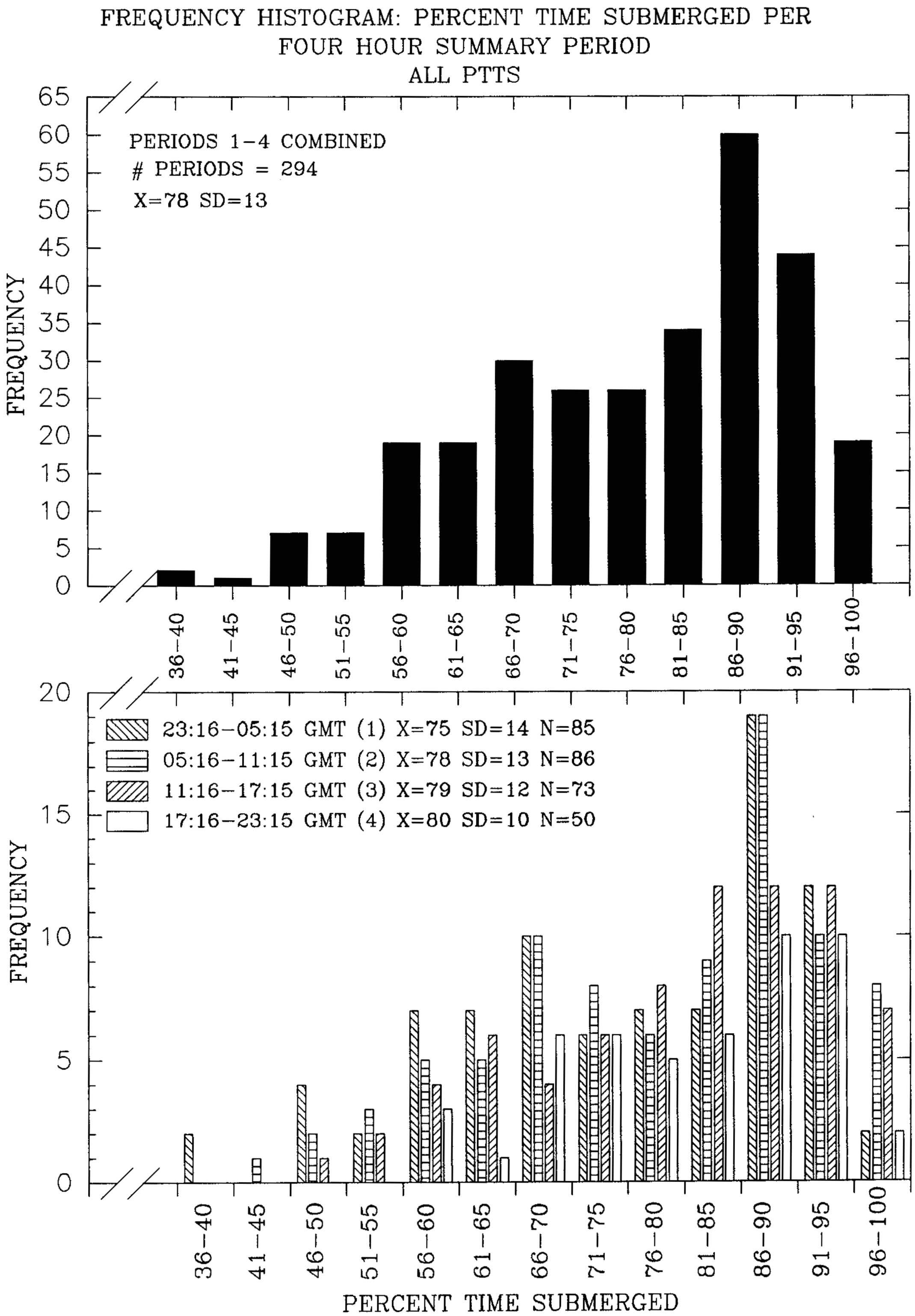


Figure 68. Frequency histogram of mean percent time submerged for all 6-hour summary periods and all 1990 PTTs combined. Note: x = mean percent time submerged (seconds); sd = standard deviation of the mean.

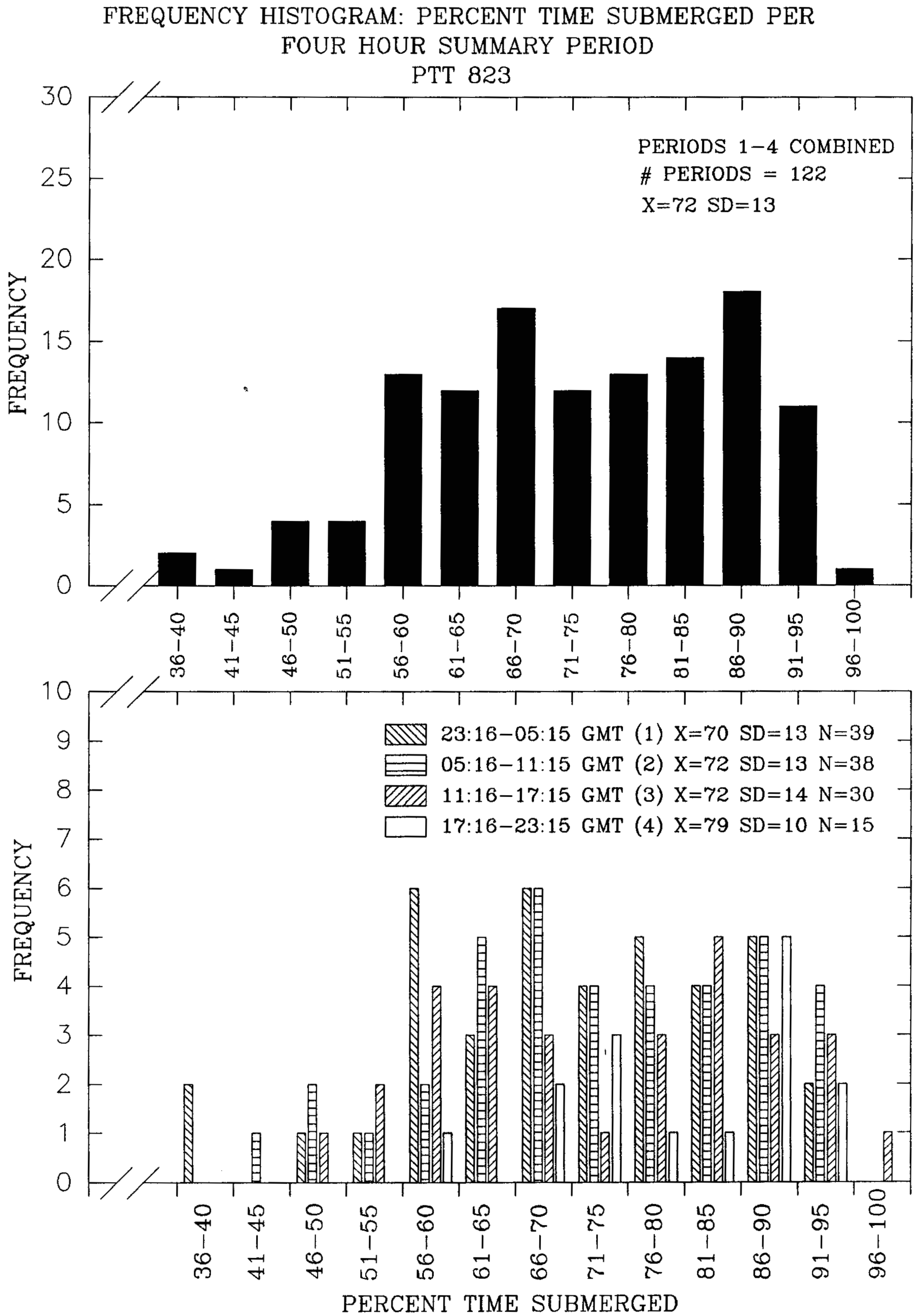


Figure 69. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #823. See note in Figure 68.

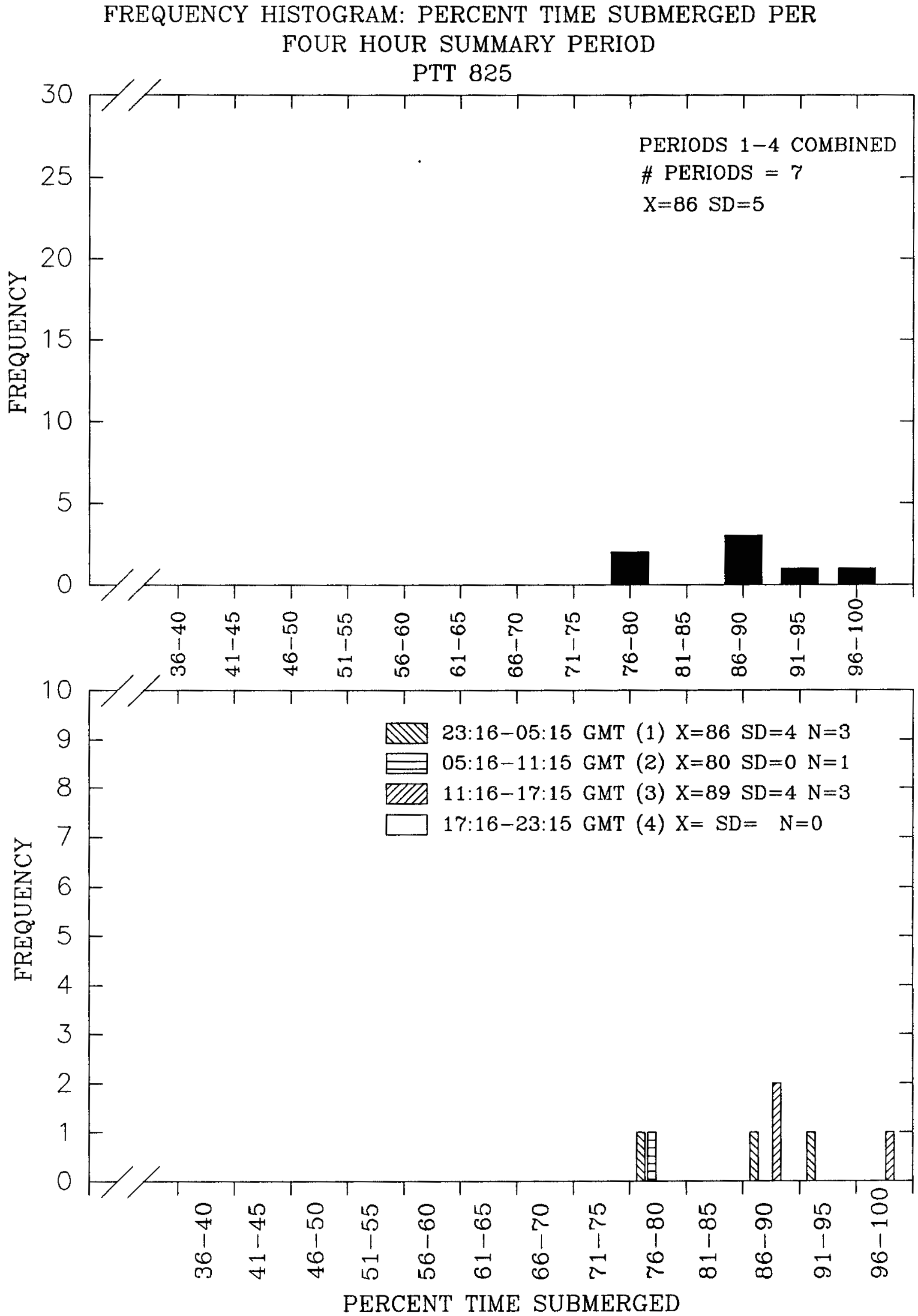


Figure 70. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #825. See note in Figure 68.

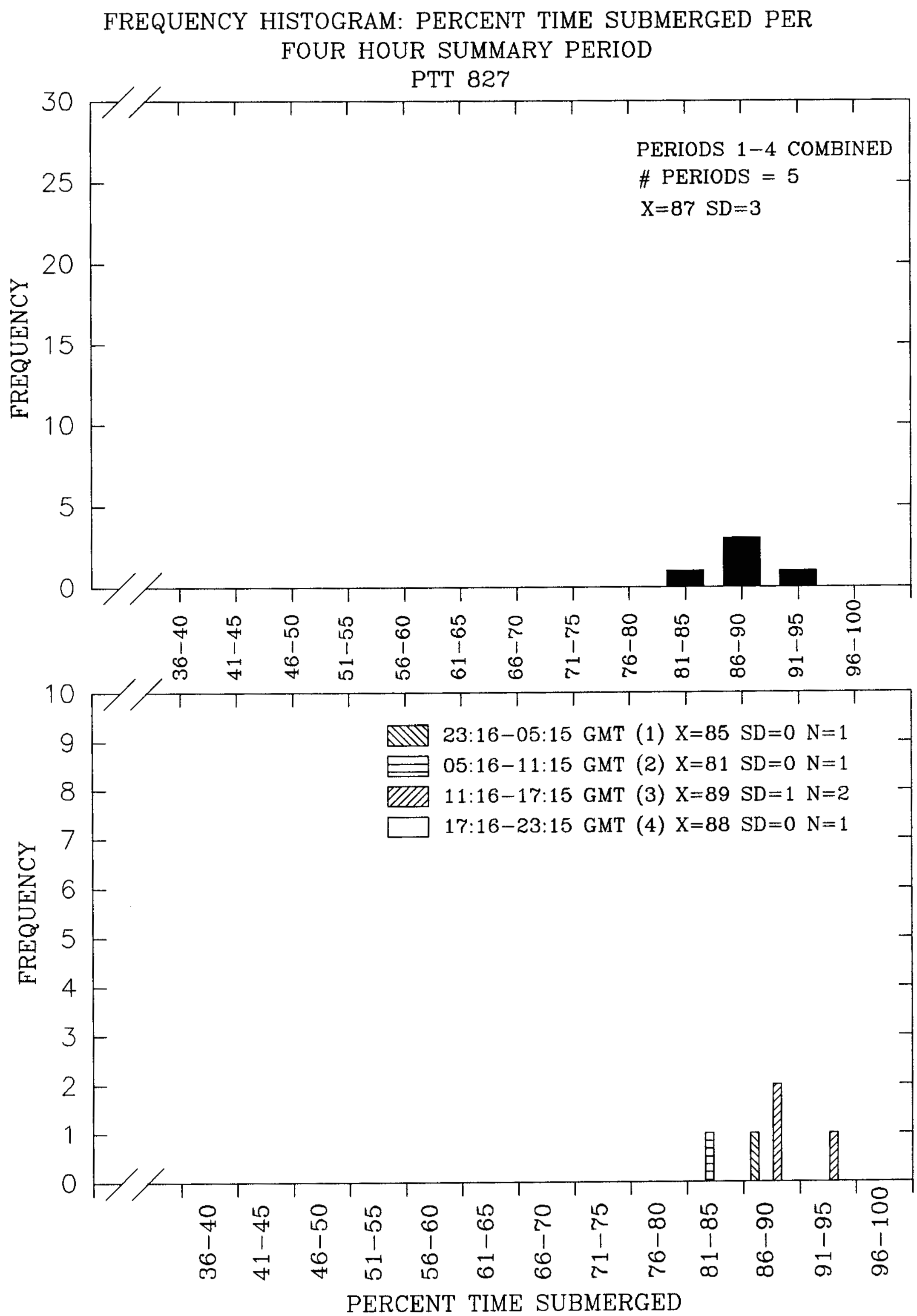


Figure 71. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #827. See note in Figure 68.

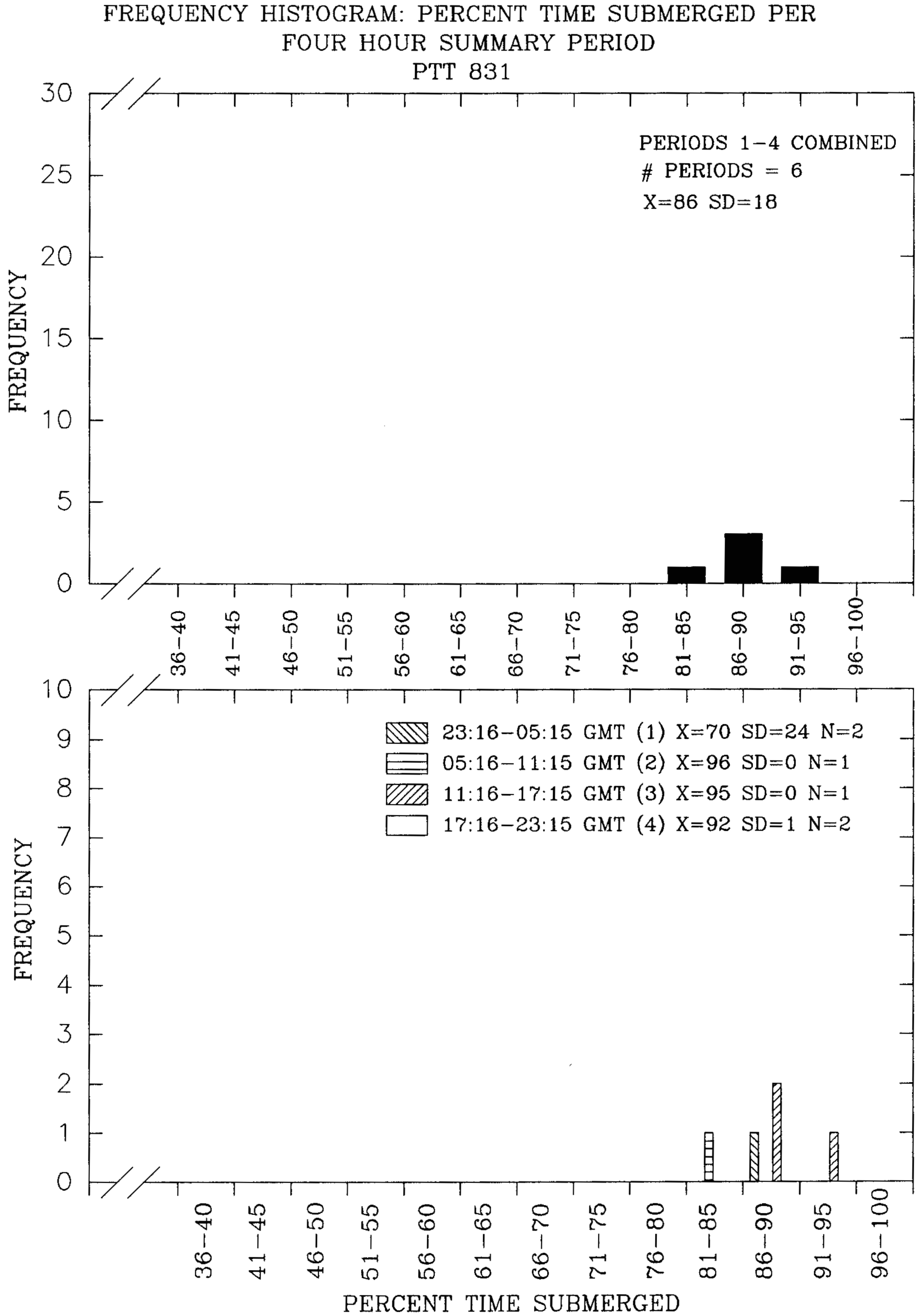


Figure 72. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #831. See note in Figure 68.

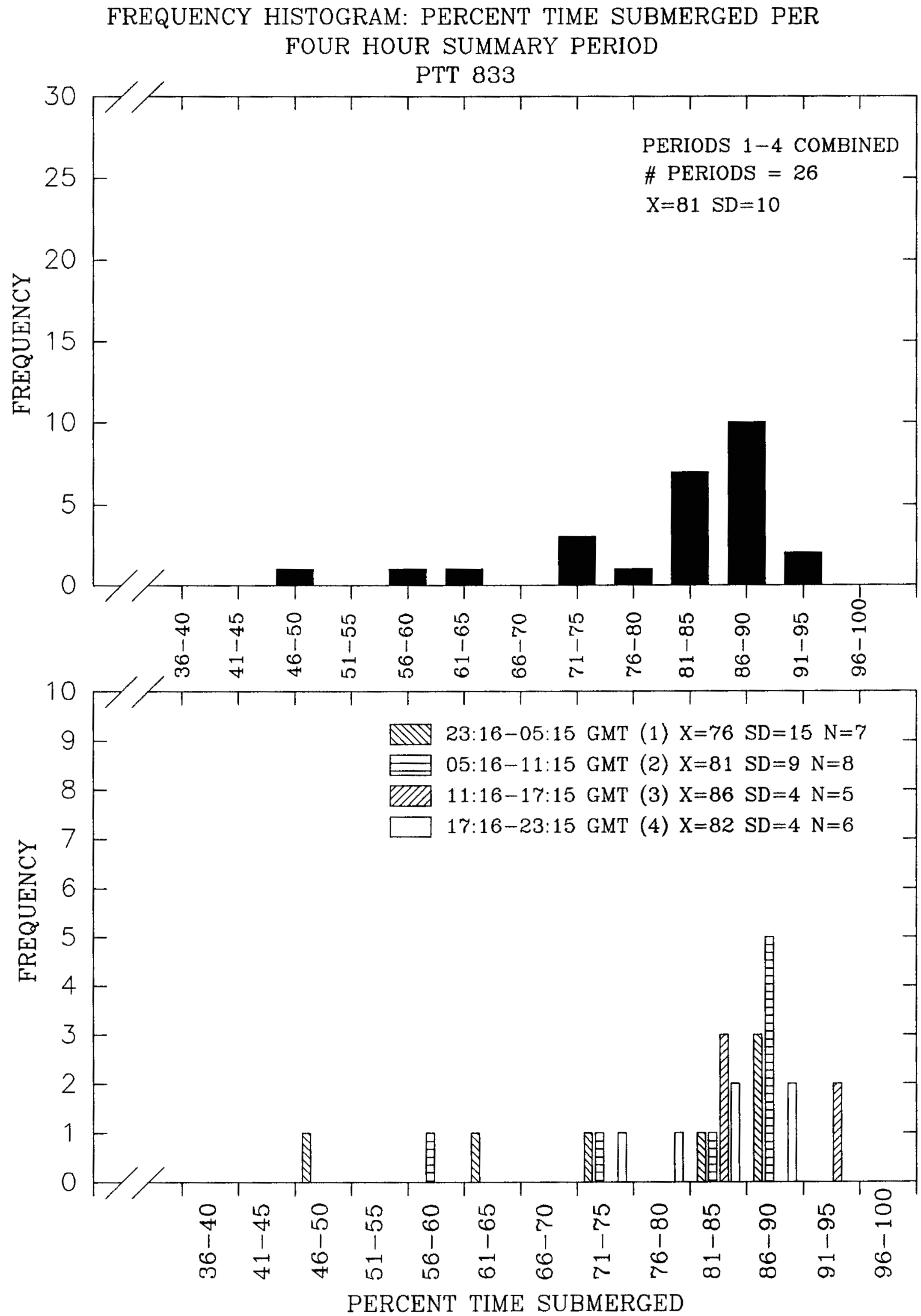


Figure 73. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #833. See note in Figure 68.

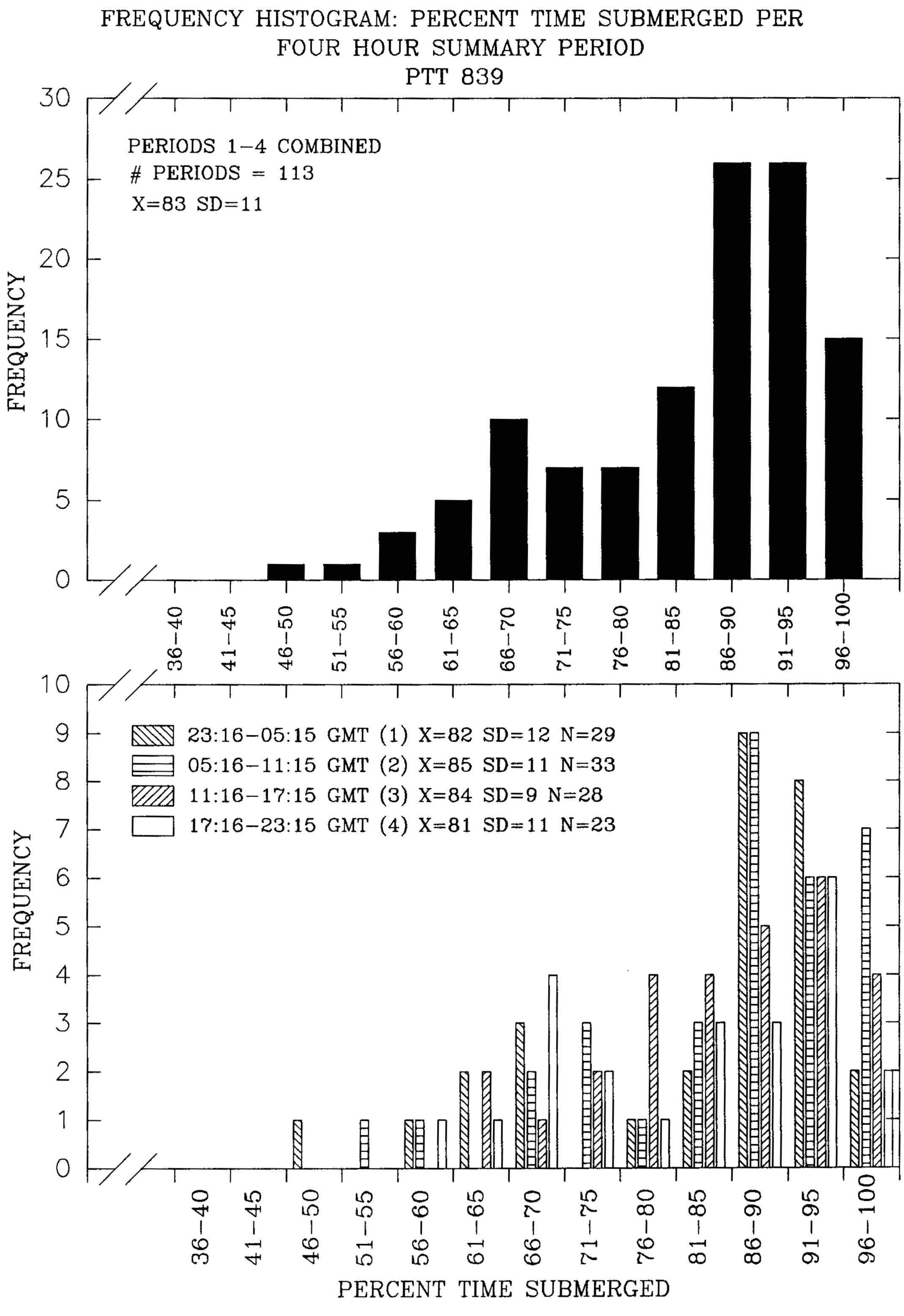


Figure 74. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #839. See note in Figure 68.

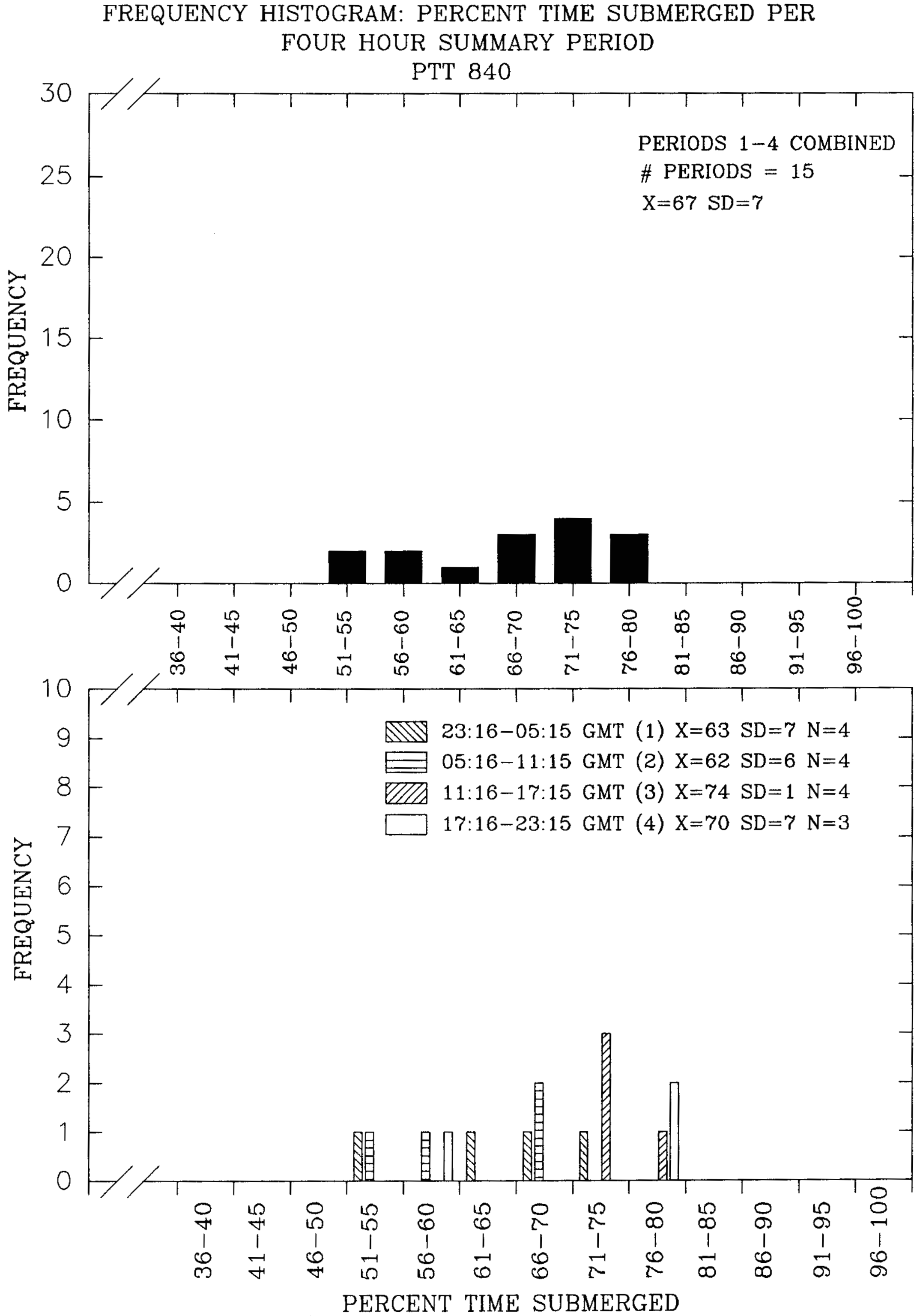


Figure 75. Frequency histogram of mean percent time submerged for all 6-hour summary periods for PTT #840. See note in Figure 68.

The frequency histogram for PTT #840 (Figure 75) demonstrates a compact range for the percentage of time spent submerged and may suggest a limited repertoire of behaviors. The frequency histograms for PTT #823 and PTT #839 (with their large sample sizes) indicate animals with much wider ranges of values but substantially different distributions. PTT #823 spent from 56% to 95% of summary periods submerged, while PTT #839 spent 81% or more of its time submerged during most periods (45% of the periods in the 86% to 95% range).

A common time base was used in Figures 76 and 77 to determine whether fluctuations in submergence time varied synchronously, perhaps in association with weather. This did not appear to be the case for the three animals with significant overlap (PTT #833, PTT #839 and PTT #823).

Surface Resting Behavior

In 1990, of 988 error-free transmissions, 361 (37%) reported a discrete dive duration of "zero." This meant that the transmitter did not go underwater for more than six seconds between transmissions (from 42 s - 54 s) and, thus, constituted what we term "surface resting." Table 15 summarizes, by period, the number of zero duration dives (ZDD) as a percentage of total error-free dives for each tagged whale. Zero duration dives accounted for 0 - 69% of all dive messages for individual whales although the time spent at the surface (from %TSUB calculations) varied from 13 - 33%. There was no trend between duration of operation and percentage of zero duration dives. If there were, it might be interpreted as an affect of tagging. We do not know if prolonged surface time is resting, recovering from oxygen debt or swimming at the surface. However, we believe whales could only swim at very slow speeds without submerging the transmitter, so we assume this activity is primarily surface resting.

The abundance of zero duration dives for animals with large sample sizes suggest that they are a normal function of whale activity and a greater proportion of their activity than previously suspected. While surface resting has been seen by many observers, there have been no studies published on this behavior in free-ranging whales which cover multiple 24-hour periods. This is the first study of large whales to document the frequency of surface resting. It is not known to what extent boat proximity may disturb or preclude this behavior. Conversely, if right whales are not disturbed easily, it may explain why they are struck by vessels so often.

"Stripe" (PTT #840) had the highest overall average percentage of ZDDs (69%), spent the most time (33%) at the surface (TSUB = 67) and also had the fastest swimming speed. PTT #839, the longest-ranging female with calf, showed 31% of her "dive" messages as surface resting activity (ZDDs) but averaged only 17% of her time at the surface. The long-range movements of the adult male (PTT #823) showed 25% of its messages in this

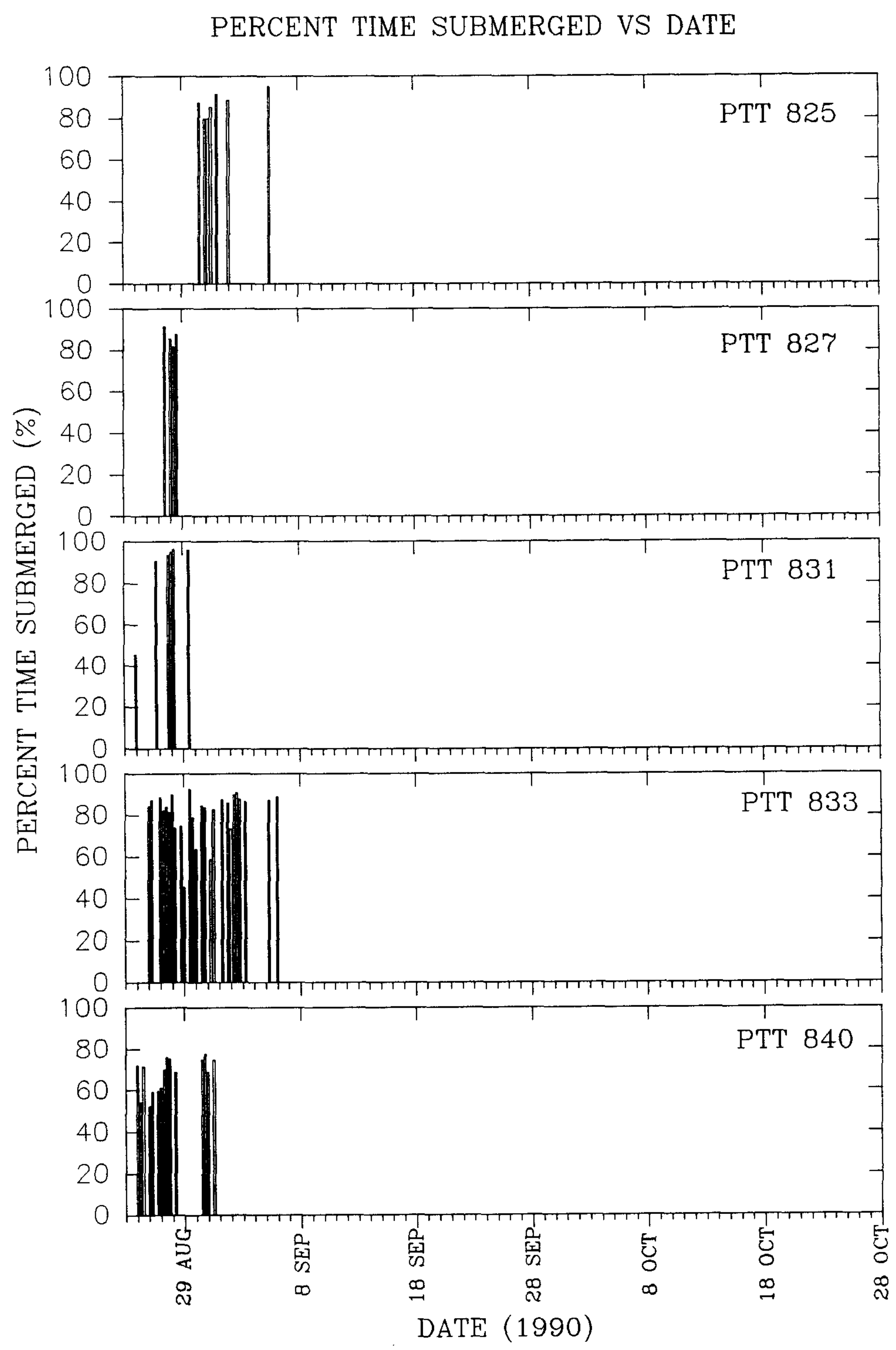


Figure 76. Chronological comparison of percent time submerged for PTTs #825, #827, #831, #833 and #840 tagged in 1990. Bars represent percent time submerged during a 6-hour summary period.

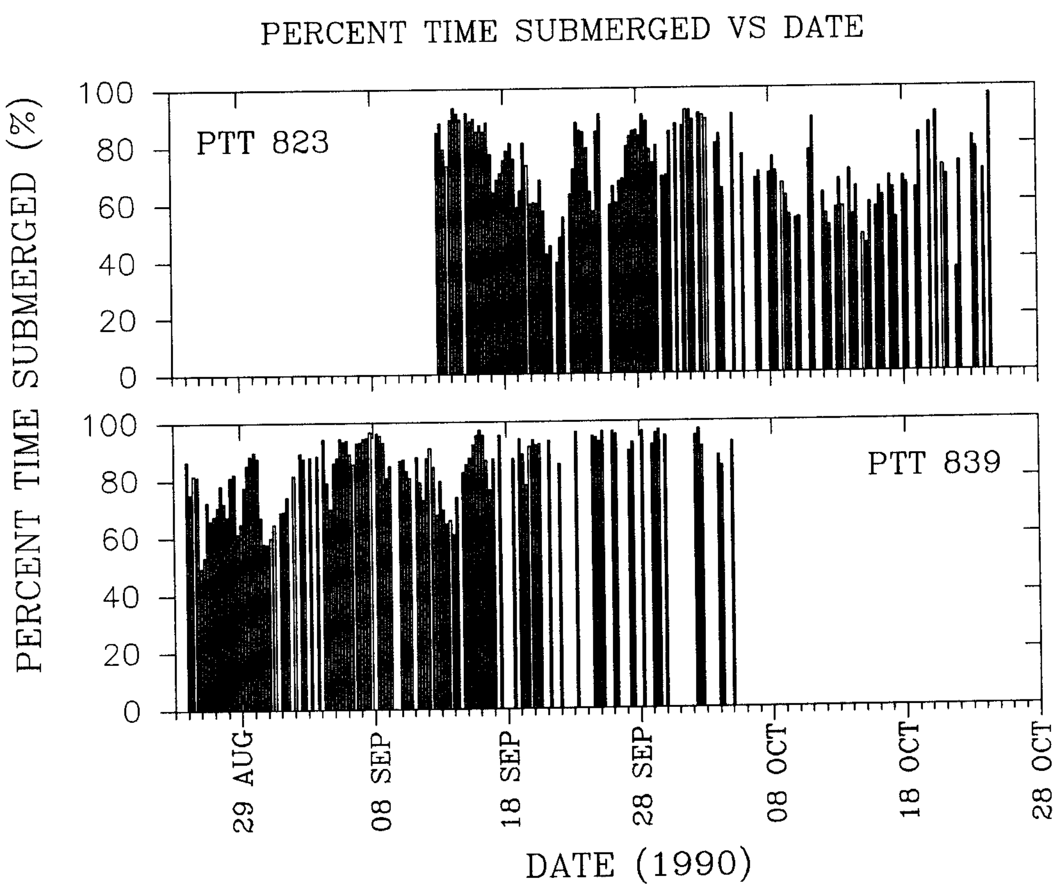


Figure 77. Chronological comparison of percent time submerged for PTTs #823 and #839 tagged in 1990. Bars represent percent time submerged during a 6-hour summary period.

DISTRIBUTION OF ERROR FREE TRANSMISSIONS WHERE DIVE DURATION = 0

	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	ALL PERIODS	TOT TRANS[1]	% OF TOTAL[2]
PTT 823	6	39	61	28	134	538	25
PTT 825	0	2	2	0	4	20	20
PTT 827	0	1	0	1	2	16	13
PTT 831	0	0	0	0	0	10	0
PTT 833	14	18	8	2	42	93	45
PTT 839	22	48	37	27	134	439	31
PTT 840	12	16	12	5	45	65	69
ALL PTTS	54	124	120	63	361	988	37

1. Total number of error free transmissions
2. Percent of error free transmissions where dive duration = 0

Table 15. Period distribution of error-free transmissions where discrete dive durations = 0.

category but spent 28% of his time at the surface. A juvenile male, which did not move a long distance had 45% of its discrete dives as ZDDs but spent only 19% of its time at the surface. These contrasts show that long-range movements and speed do not by themselves dictate surface resting patterns and that percentage ZDD is an important but not exclusive indicator of total time spent at the surface. Also, the frequency of surface resting during Periods 2 and 3 probably contributed to the high number of messages received during those periods.

Often zero duration dive (ZDD) messages occurred one after another, confirming long periods of surface resting. The longest series of zero duration dive messages accounted for a total of 11 min. spent continuously at the surface by PTT #833. With just a few dives of less than 20 s, prolonged surface resting was apparent for up to 12 min. for PTT #823, 10 min. for PTT #839 and 7 min. for PTT #840. Often consecutive monitored passes up to six hours apart showed long periods of surface resting. Figure 78 demonstrates the relationship between the percentage of time spent submerged and the number of zero duration dives. As suspected, large numbers of zero duration dives were recorded most frequently during summary periods which reported a higher percentage of surface time (low percent of time spent submerged). The strong similarity in the equations fitted to data for PTT #823 and PTT #839 suggest that this relationship is reasonably stereotyped, especially considering the differences in the number of dives and average dive durations for these two animals.

The Relationship of Speed and Respiration Patterns

Figures 79 - 82 show the chronological relationship of average dive duration, speed and the number of dives in a 6-hour summary period for the four whales with the largest sample sizes. It is important to re-emphasize that speeds used here are minimum estimates based on calculated distances between Argos acquired locations. Thus, our calculated high speeds may be the real result of extremely directed (linear) swimming activity or errors in Argos locations.

Figure 83 shows the relationship between average dive duration, number of dives and speed for all 6-hour summary periods and for all whales. An upper limit to this curve is described by the function:

1990 average duration of dive = # seconds in period/# dives
AVG DUR = (21,600)/(#DIVES)

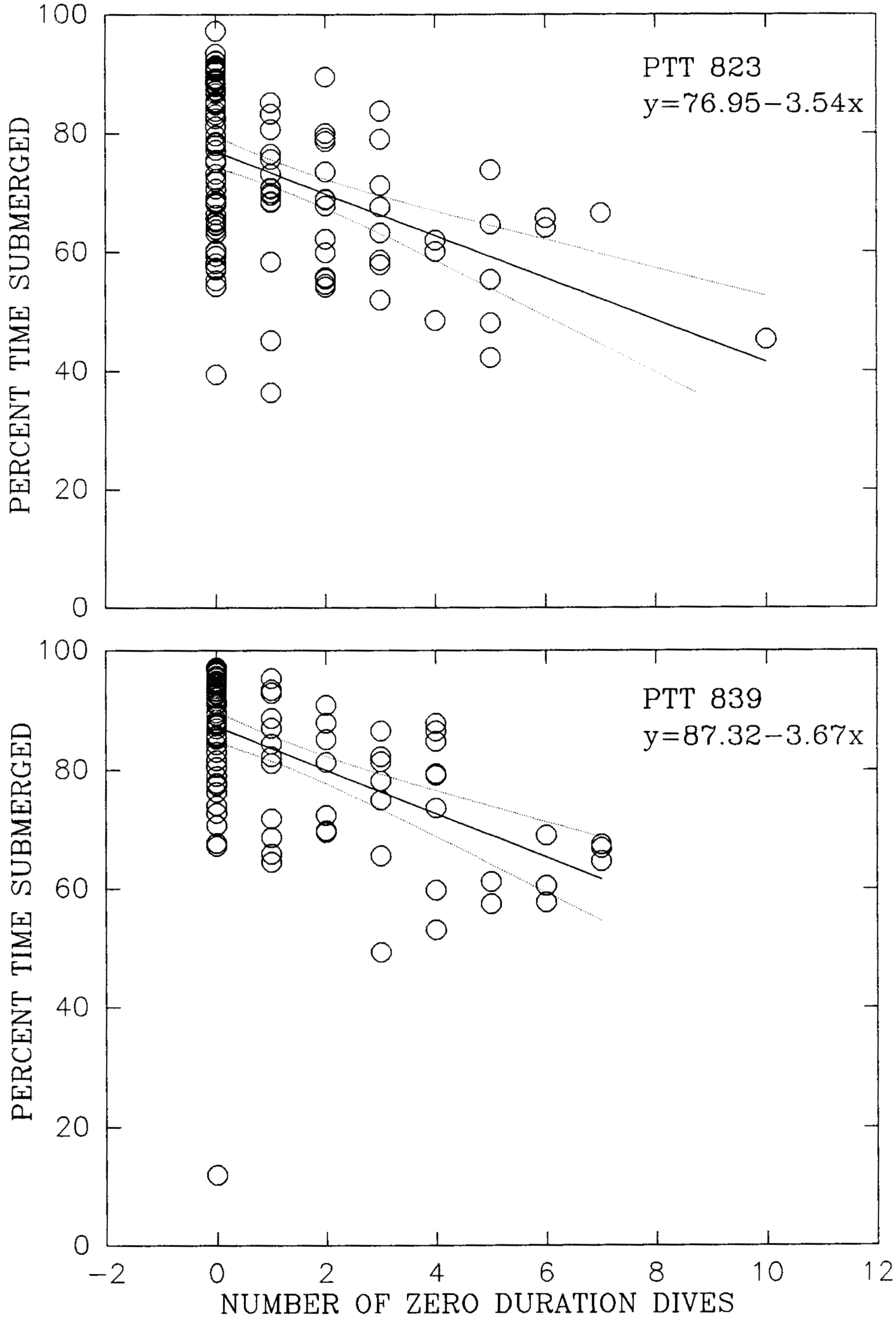


Figure 78. Number of zero-duration dives per 6-hour period versus percent time submerged (PTTs 823 and 839).

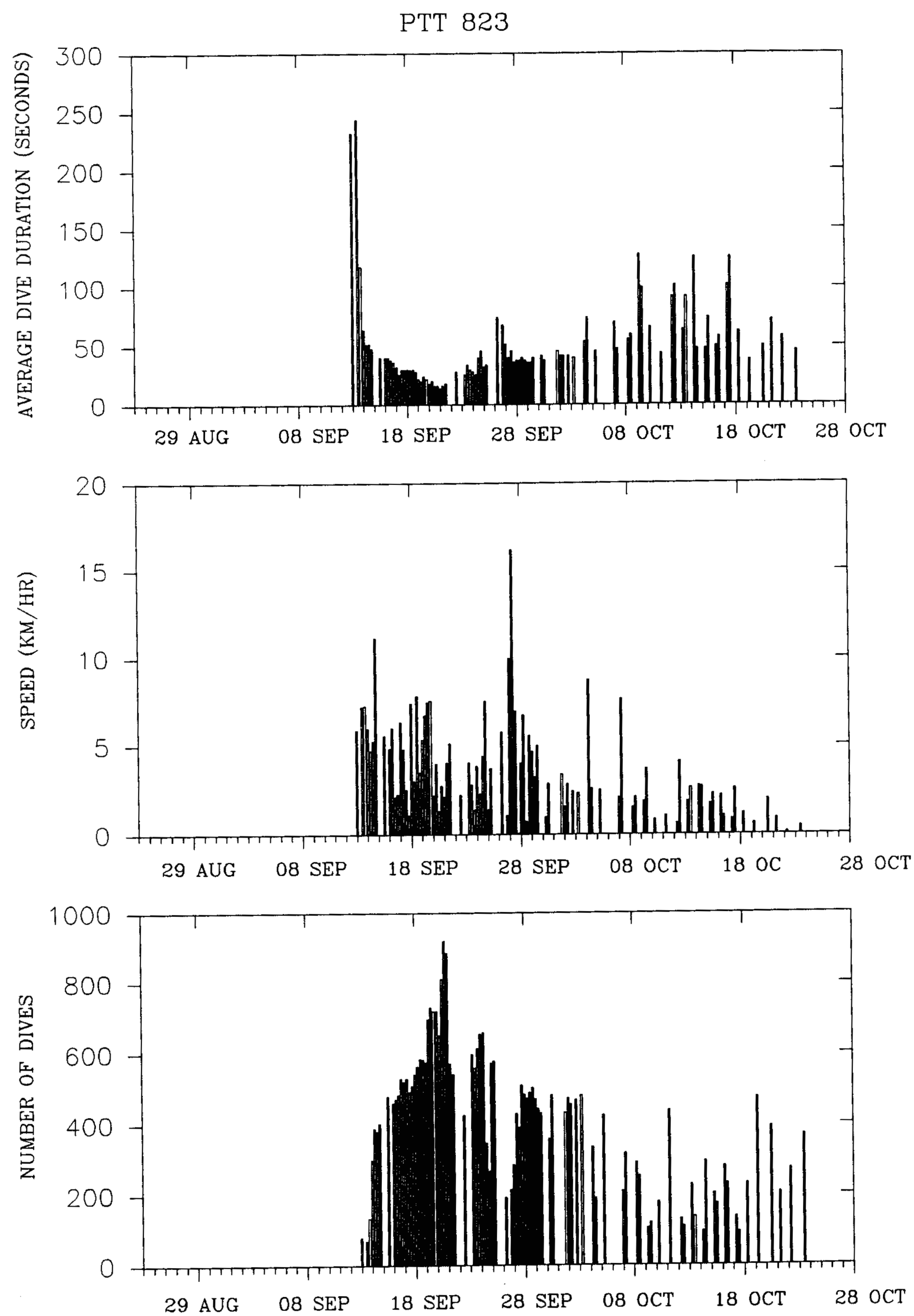


Figure 79. The chronological relationship of average dive duration, speed and number of dives for PTT #823.

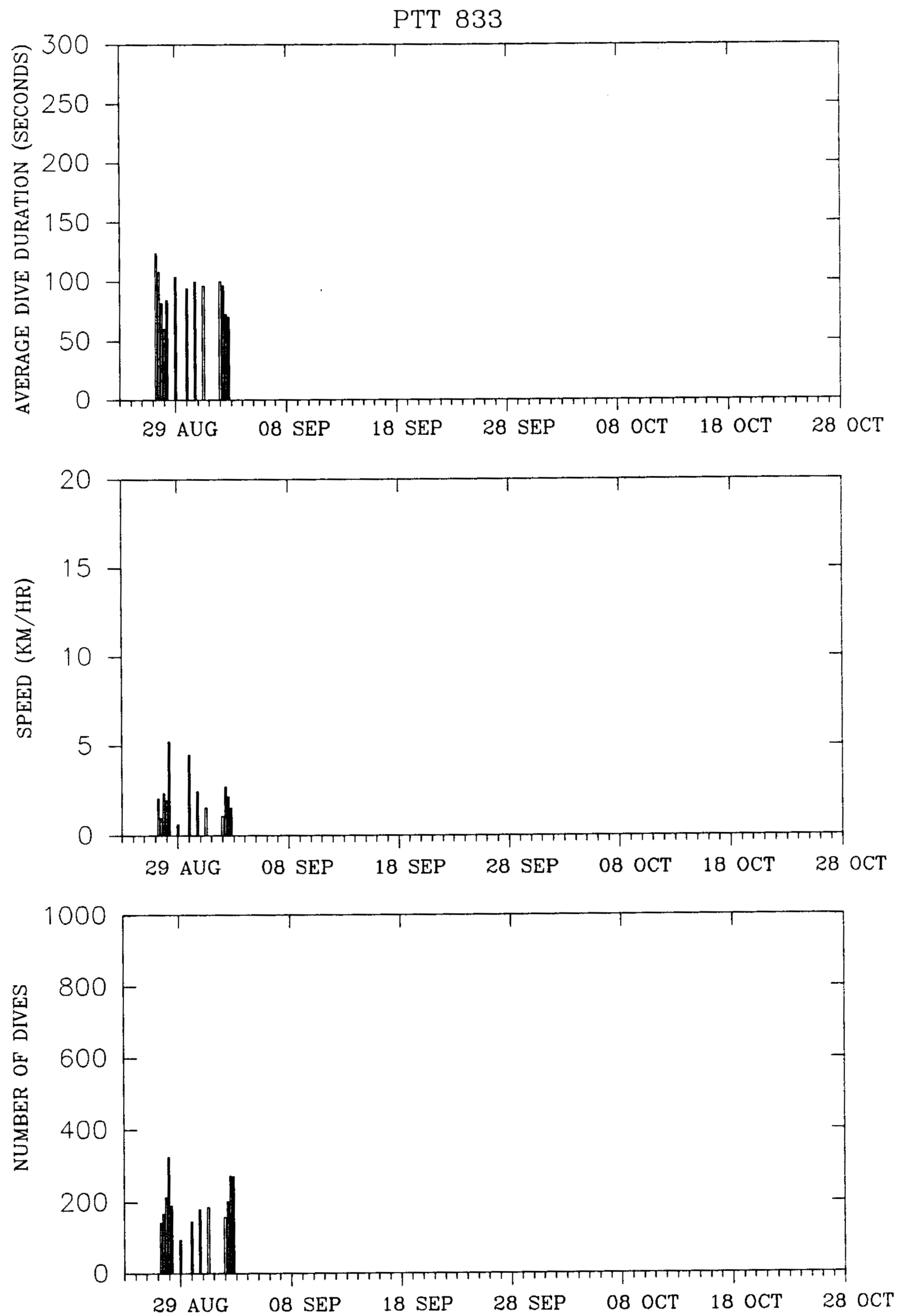


Figure 80. The chronological relationship of average dive duration, speed and number of dives for PTT #833.

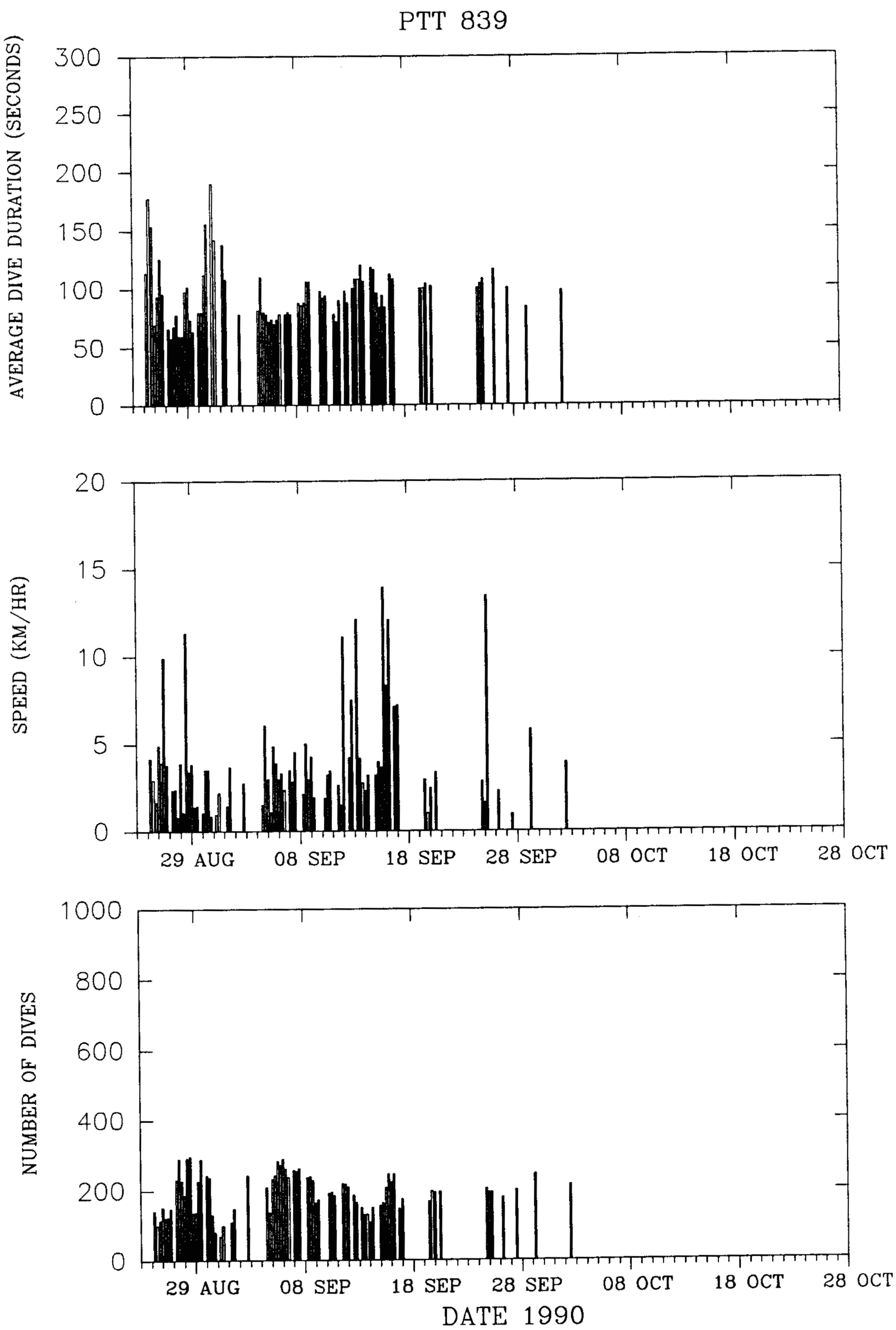


Figure 81. The chronological relationship of average dive duration, speed and number of dives for PTT #839.

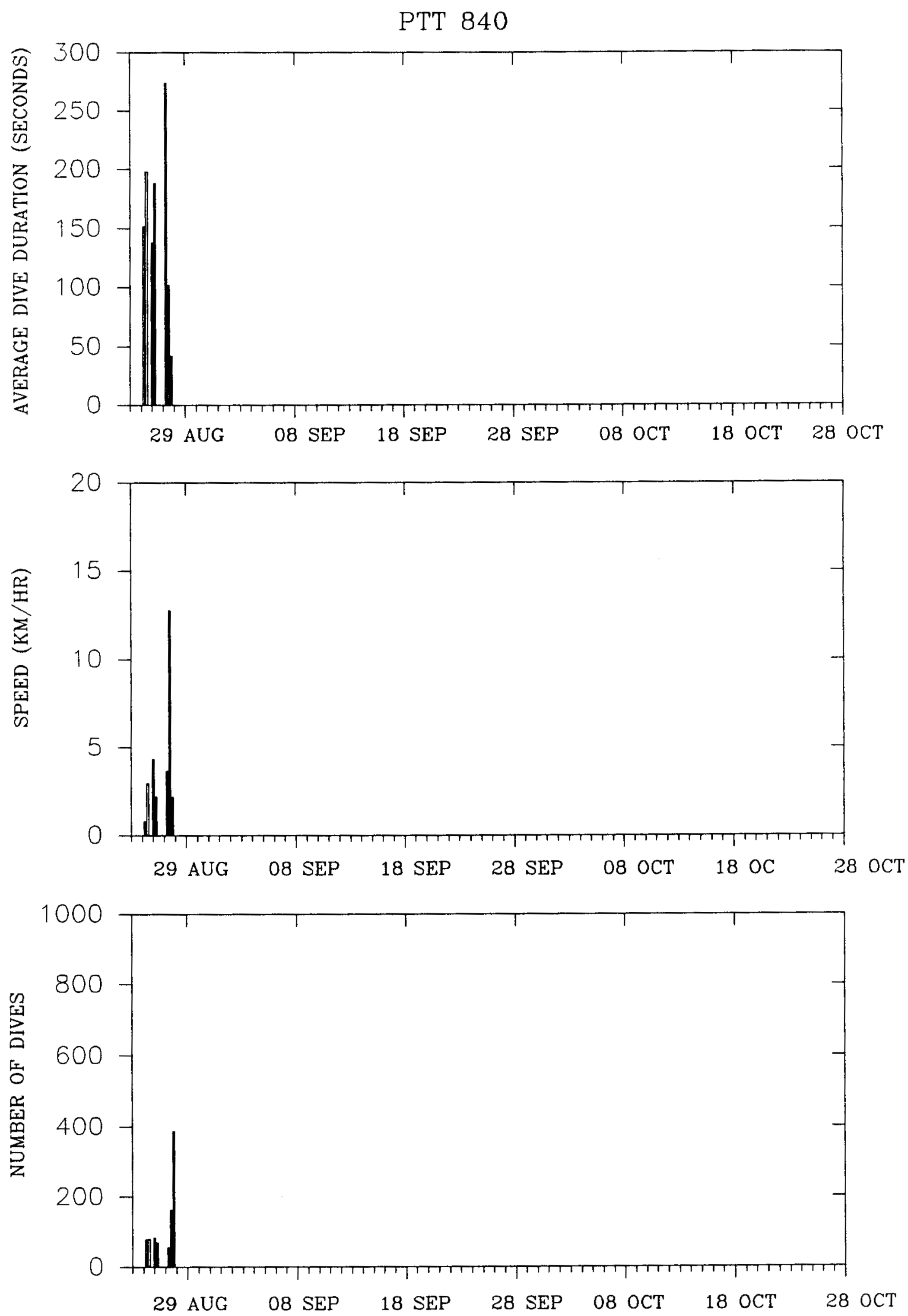


Figure 82. The chronological relationship of average dive duration, speed and number of dives for PTT #840.

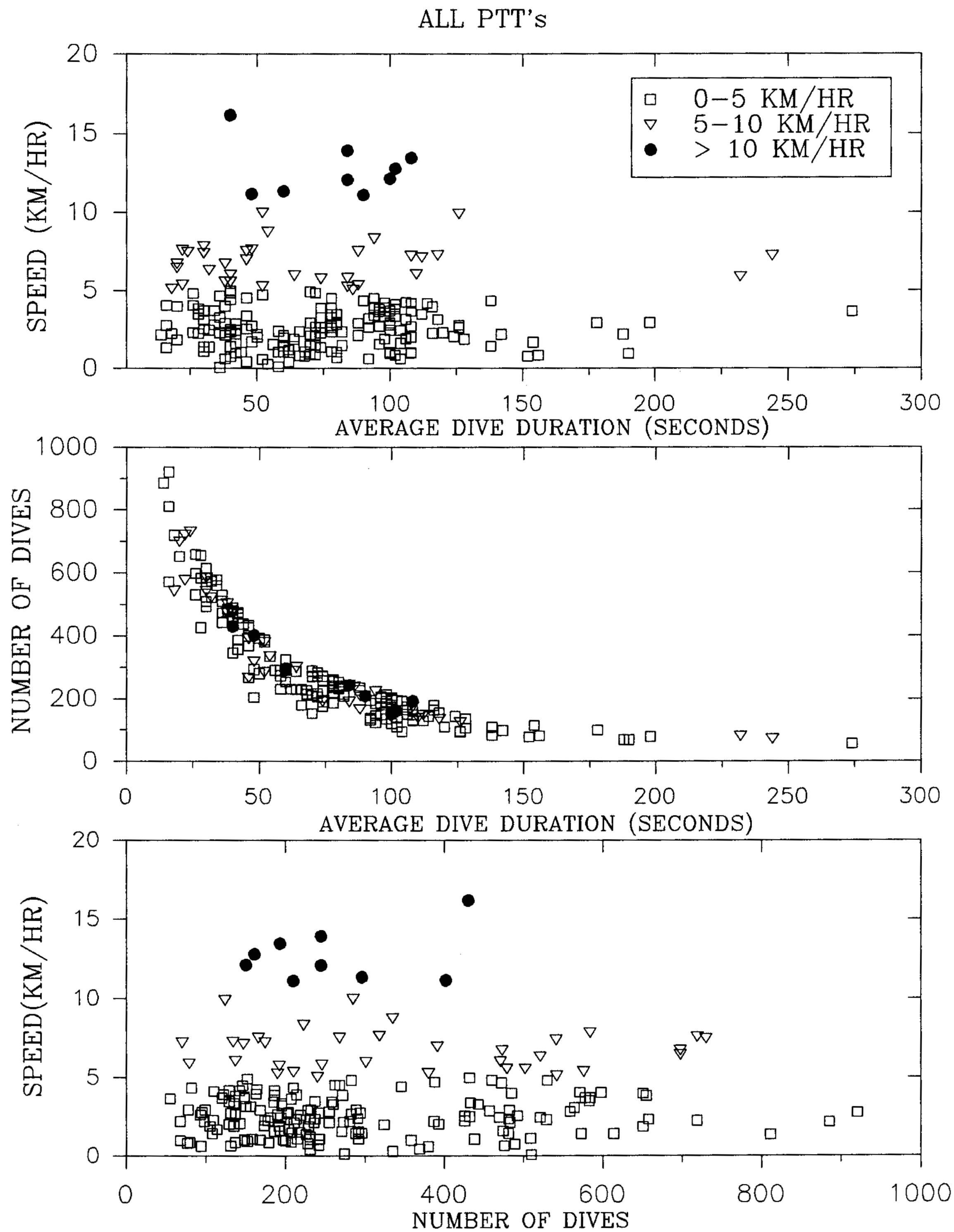


Figure 83. The relationship of: A) speed to average dive duration; B) number of dives versus average dive duration; and, C) speed versus number of dives for all PTTs.

This represents the maximum average dive duration if the entire 6-hour period were divided by varying numbers of dives. In this figure, the vertical divergence of points from the theoretical upper limit describes the amount of time the animal spends at the surface. Higher travel speeds tend to be close to the upper limit of the curve, implying minimum surface time, and are also clustered in the central portion of the curve suggesting an optimal aerobic strategy. However, there apparently is not a single optimal dive (respiration) pattern for right whales. The difference in respiratory strategies is apparent by comparing Figure 84b (adult male, PTT #823: larger numbers of short duration dives) and Figure 85b (female with calf, PTT #839: smaller numbers of longer duration dives). From these figures, speed does not appear to be directly related to either average dive duration or numbers of dives, and average duration does not appear to be a direct inverse proportion to number of dives. The high speed data, although close to one another, do not overlap. Figures 86 and 87 depict similar relationships for juvenile PTT #833 and adult female PTT #840. Both more closely resemble PTT #839. It is impossible to say, at the present time, whether these differences are due to age, sex, reproductive status or individual variability.

Oceanographic Factors

Temperature Profiling

1989

The temperature sensor in 1989 was located outside the transmitter. The transmitter recorded the temperature of the water at the maximum depth of dive. Thus, we used data from dives to varying depths and from several days to compile composite temperature/depth profiles for PTT #843 east and northeast of Jeffrey's Ledge (Figure 88). Both profiles are similar and do not show sufficient detail to discern a sharp thermocline.

1990

Right whale tags in 1990 were equipped with a temperature sensor inside the tags. When whales returned from longer dives, the reported transmitter temperature was often lower than the surface water, suggesting deep dives into temperature-stratified waters. Without temperature profiles for these areas, we are presently unable to interpret the specific dive depths accomplished. In the future we hope to obtain temperature profile information from oceanographers maintaining offshore buoys in the areas.

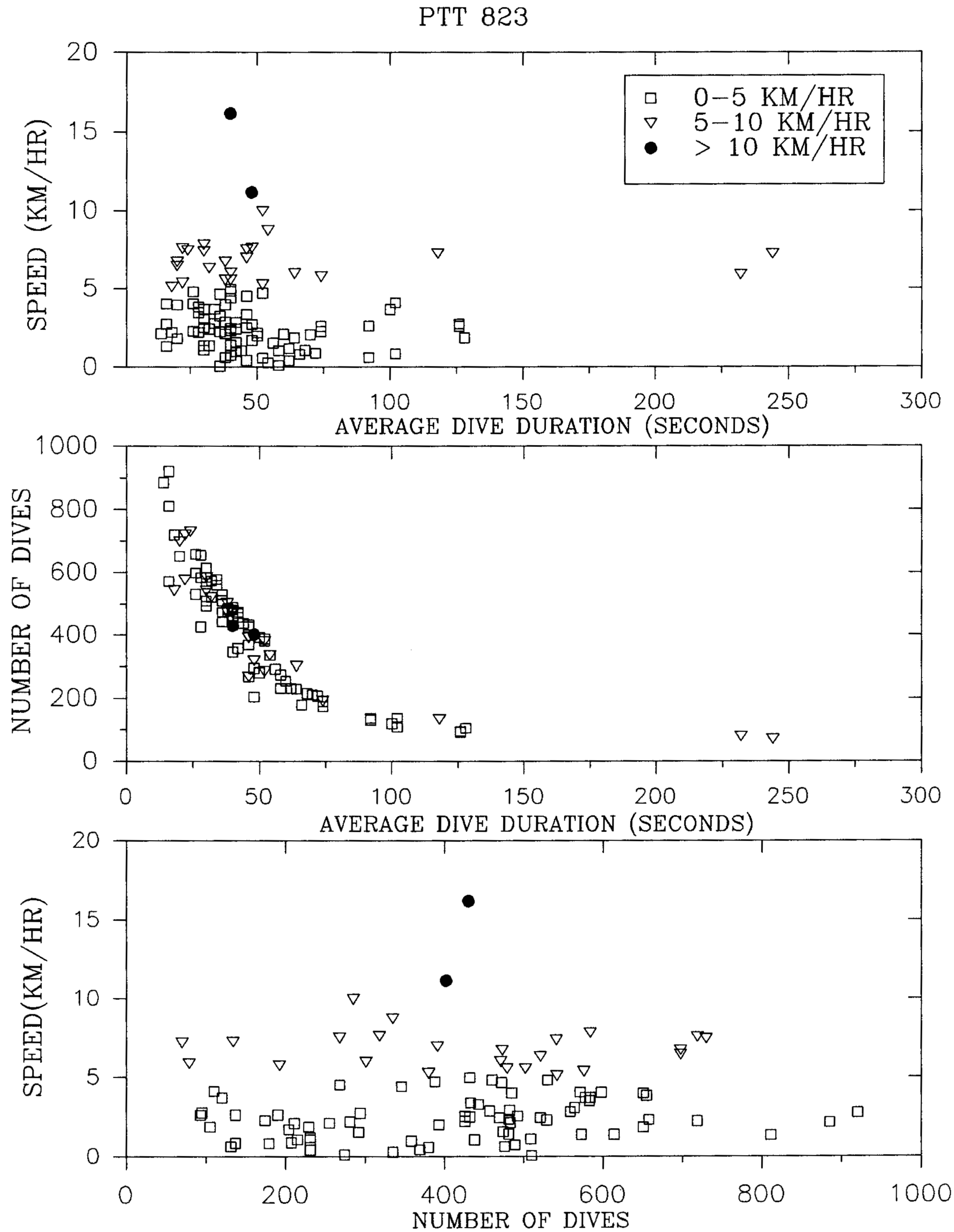


Figure 84. A) the relationship of speed to average dive duration; B) number of dives versus average dive duration; and C) speed versus number of dives for PTT #823.

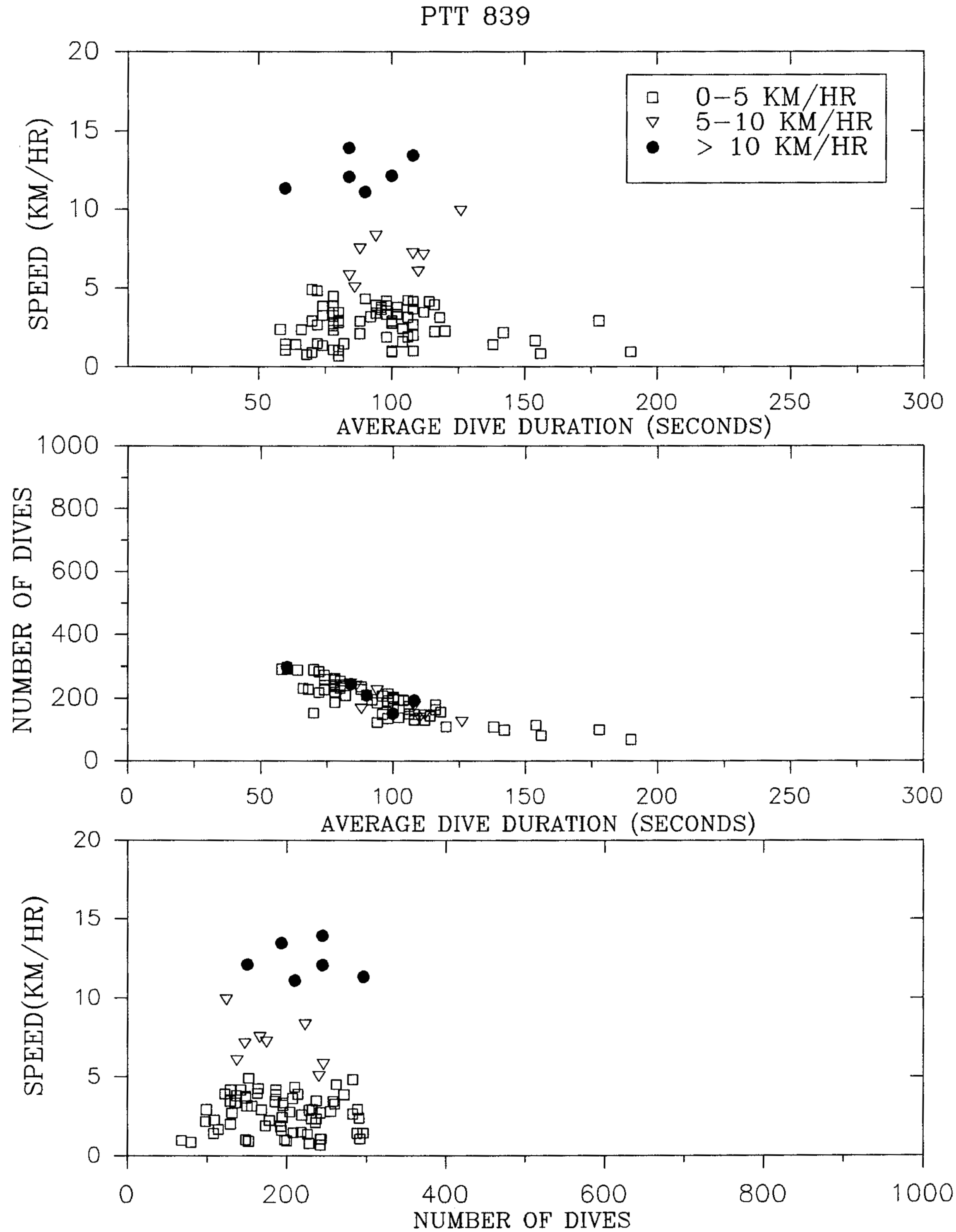


Figure 85. A) The relationship of speed to average dive duration; B) number of dives versus average dive duration; and C) speed versus number of dives for PTT #839.

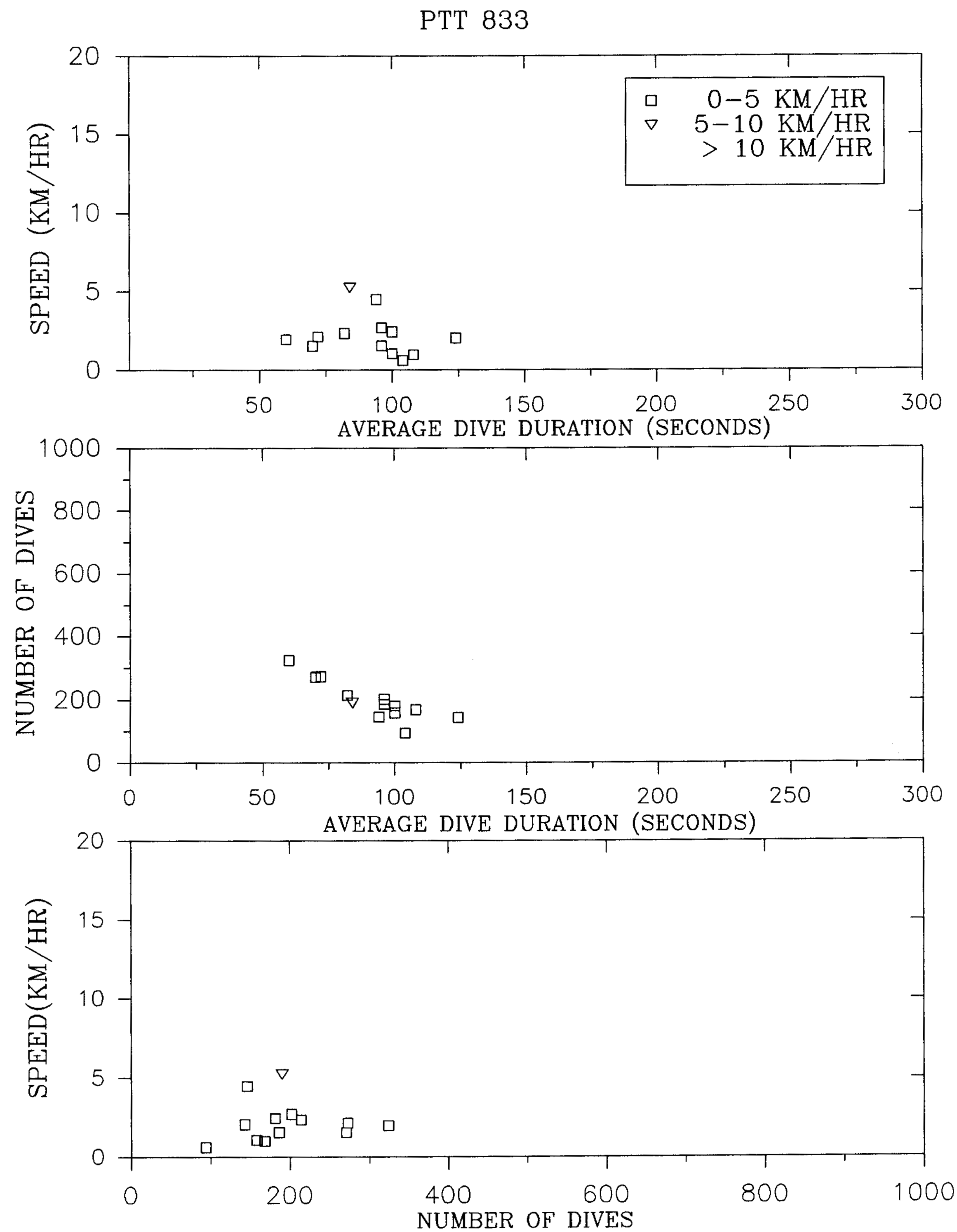


Figure 86. A) The relationship of speed to average dive duration; B) number of dives versus average dive duration; and C) speed versus number of dives for PTT #833.

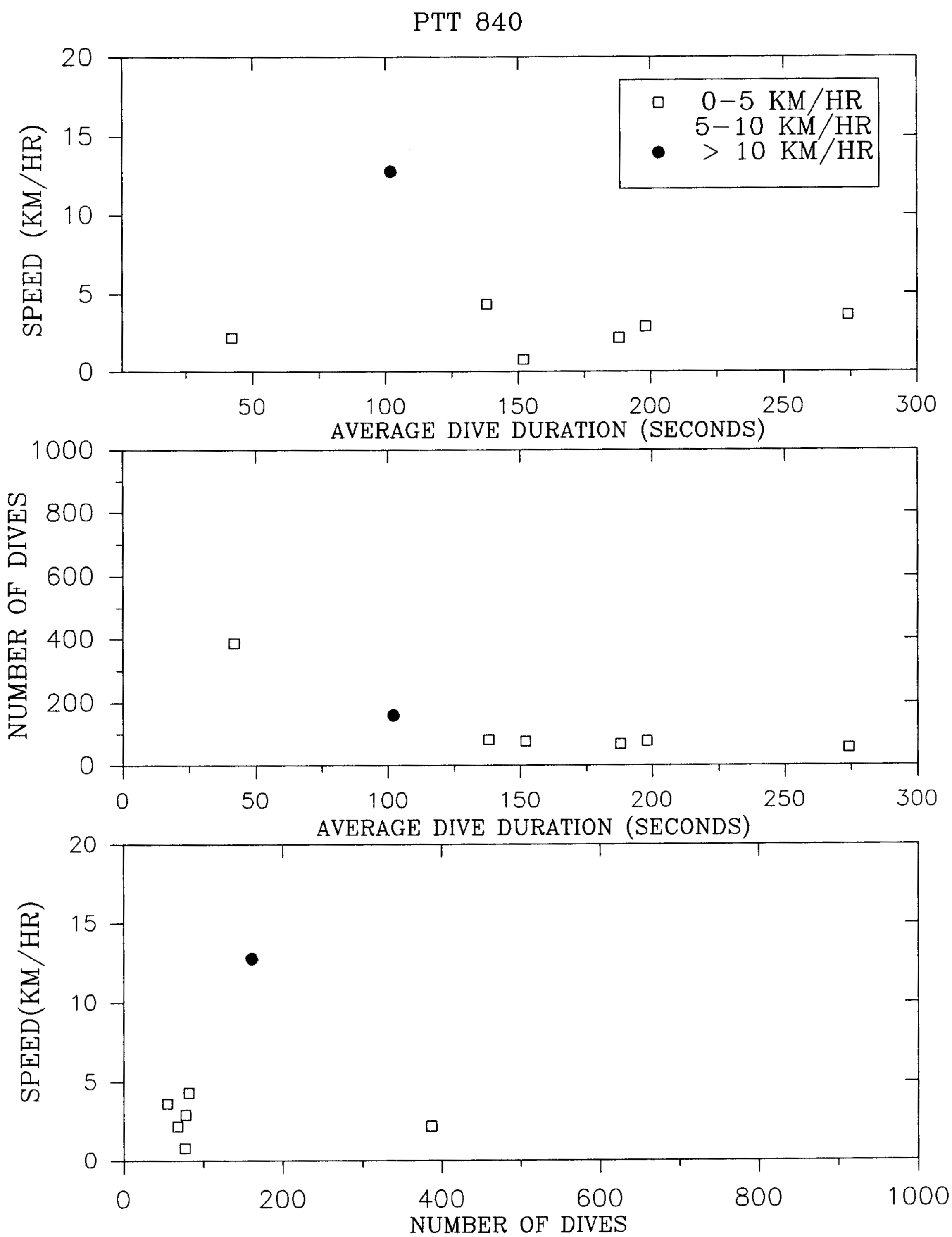


Figure 87. A) The relationship of speed to average dive duration; B) number of dives versus average dive duration; and C) speed versus number of dives for PTT #840.

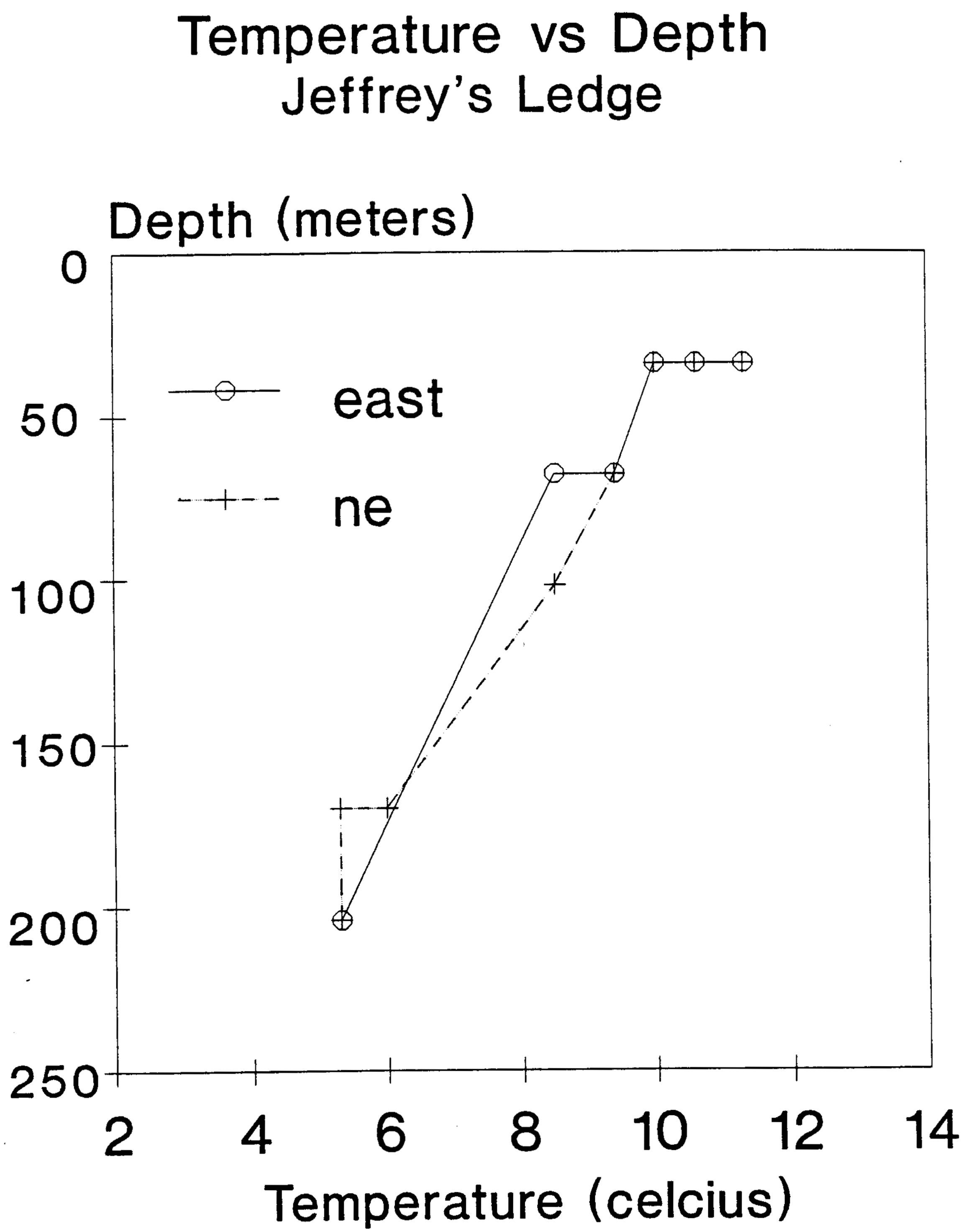


Figure 88. Water temperature (C^o) versus depth of dive (meters) for PTT #843 in the western Gulf of Maine (Oct/Nov. 1989).

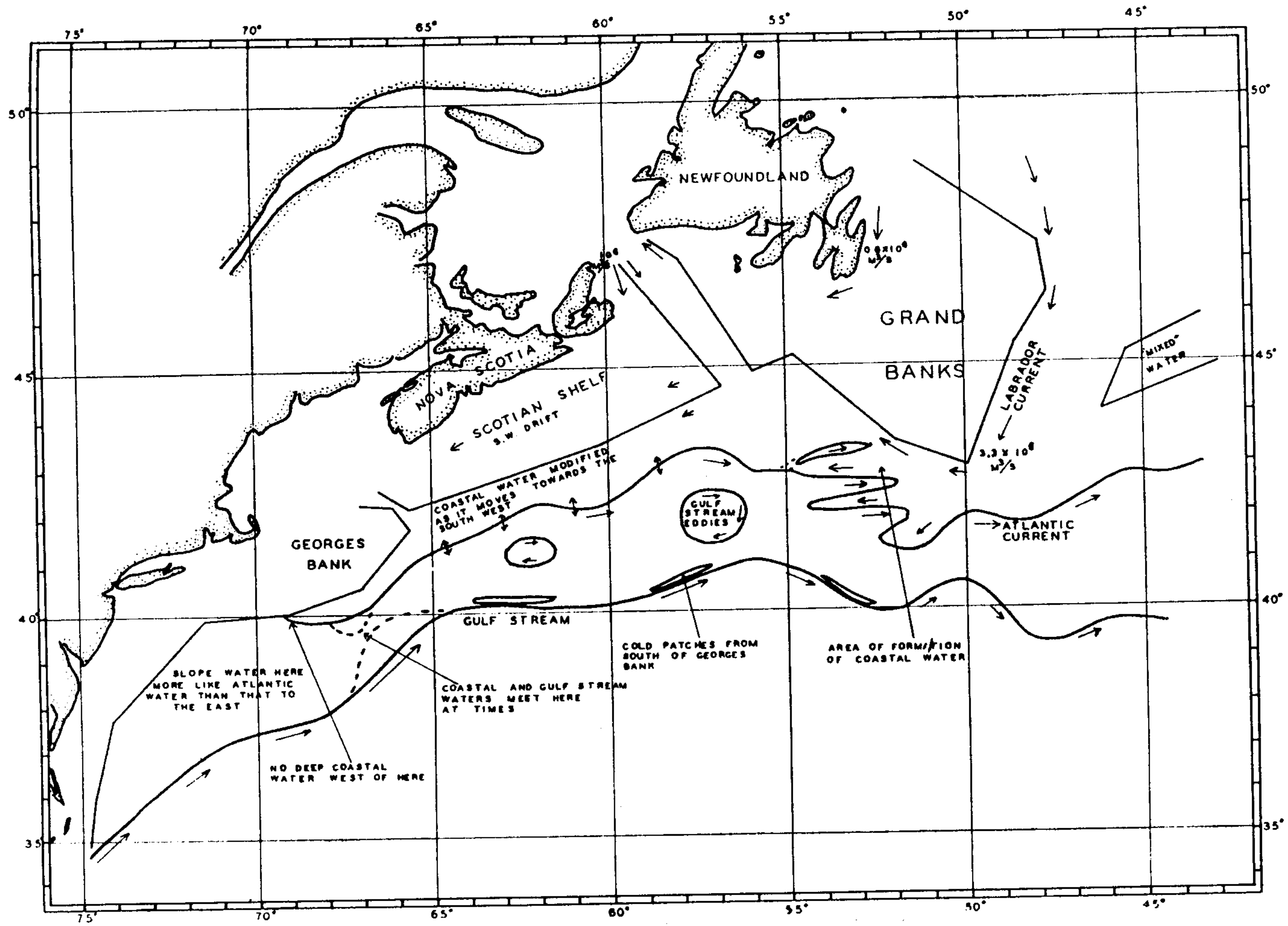


Figure 89. A map of the Northwest Atlantic showing the general circulation in the shelf and slope waters (after McLellan, 1957).

Study Area Characteristics

Figure 89 shows the Labrador and Nova Scotia currents as well as the Gulf Stream in relation to the Gulf of Maine (GOM). GOM water circulates in a counter-clockwise fashion and explains why temperature profiles east and northeast of Jeffrey's Ledge are so comparable. GOM water exits southerly around Cape Cod via the Great South Channel and to the south after going clockwise around George's Bank. Water leaving the GOM continues southwesterly on the New England Shelf as a weak nearshore shelf current. Slightly further offshore, slope waters parallel the southerly shelf water movements. Even farther offshore, the Gulf Stream flows north, then east paralleling the continental slope contours (Butman and Beardsley, 1987). In the western Gulf of Maine there is a small clockwise eddy northeast of Jeffrey's Ledge (Bigelow, 1927).

Sea Surface Temperature

The documented movements and dive characteristics of three whales (PTT #843, PTT #823 and PTT #839) during this project appear to be correlated with certain oceanographic factors/processes. We obtained sea surface temperature images of the study area from the NOAA Marine Climatology Investigation at the University of Rhode Island Remote Sensing Laboratory. Movements of the whales with longer tracks (PTT #823 and PTT #839) were plotted over the temporal oceanographic features. Selected images are provided here but, regrettably, do not reproduce well in black and white. Readers working from an NTIS copy may wish to consult one of the color masters on file with MMS in the Alaska or the Atlantic Regional Office or MMS headquarters in Washington, D.C.

The temperature scale reads as follows:

White	=	Cloud cover
Red	=	2 - 5°C
Blue	=	7 - 10°C
Green	=	11 - 18°C
Yellow	=	19 - 24°C
Orange	=	25+°C

Figure 90 shows the movement of a female (PTT #839) with a calf along the convergence of a warmer (offshore) and cooler (nearshore) body of water. By 16 September this whale had moved around Cape Cod and was crisscrossing a region of cold water east of Long Island Sound. This zigzag pattern may be an attempt to stay in a nutrient dense patch of food.

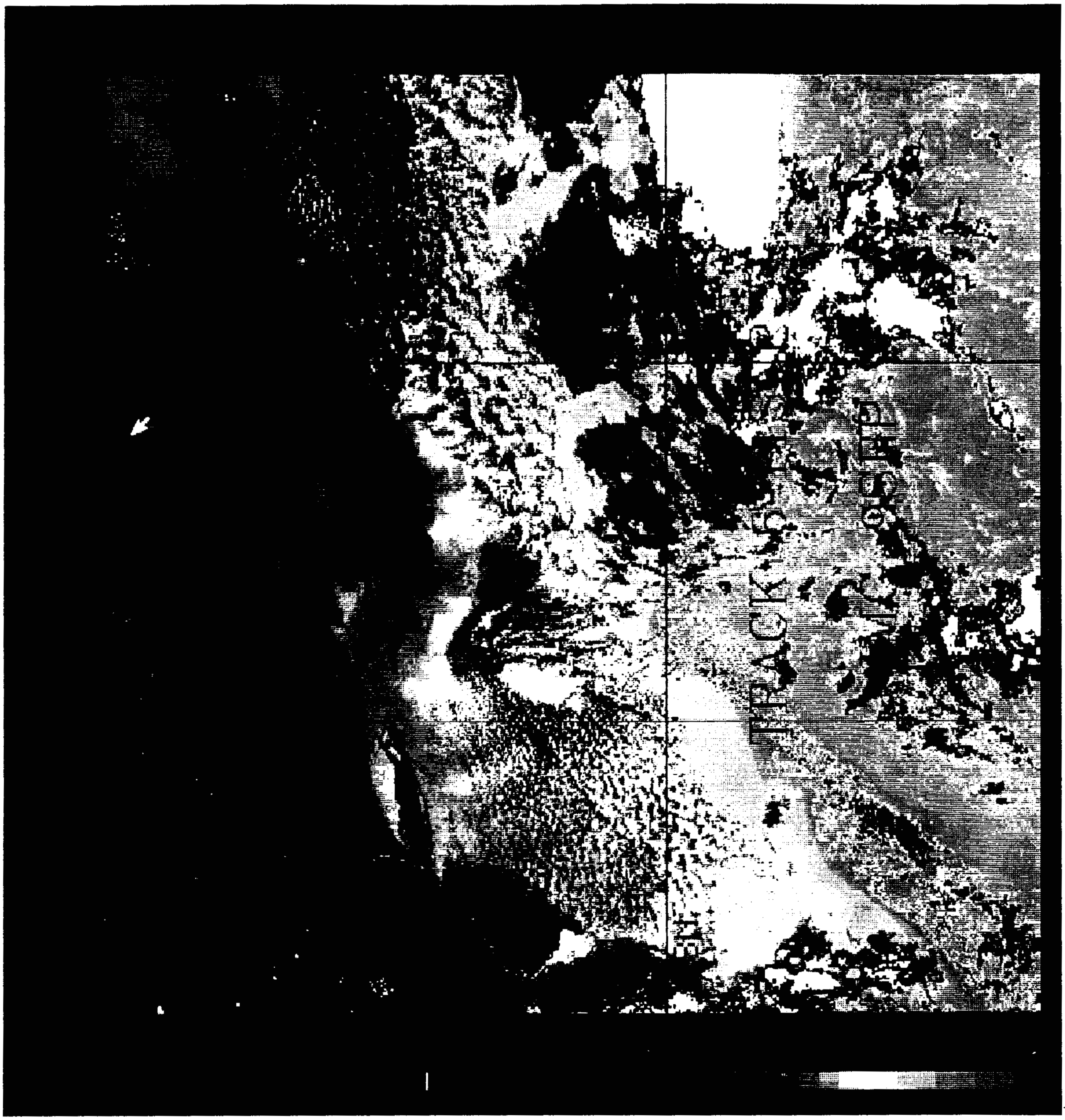


Figure 90. NOAA satellite-monitored sea surface temperatures. This color image is a composite of data collected by the URI/NOAA Remote Sensing Lab on 9 September 1990 and shows the track of PTT #839 along a convergence zone.

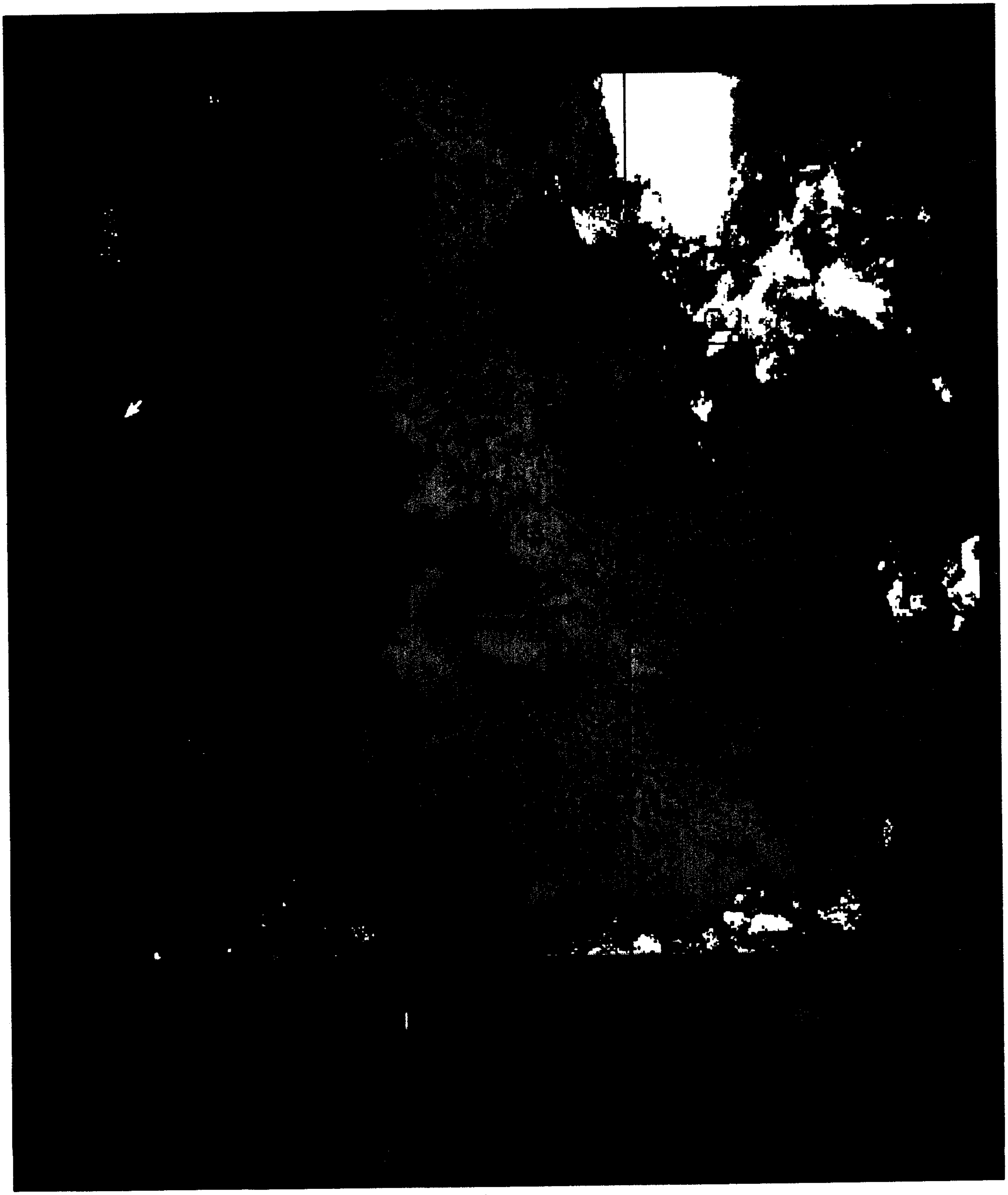


Figure 91 is a composite of 21 - 22 September and shows PTT #823 moving along the eastern edge of a warm core ring where cooler, nutrient-rich shelf water was being entrained around the ring. This feature, associated with warm core rings, is visible at the surface as a narrowing funnel of colder water and is a potential mechanism for concentrating prey. The occurrence of rings in this area is reasonably common (Wiebe, 1982) but it is not known if this whale knew of this phenomenon through previous experience or just happened upon it. PTT #823 continued south to the north wall of the Gulf Stream where prey are often concentrated. The whale then moved north. By 16 October (Figure 92), PTT #823 moved to an upwelling area off the southern tip of Nova Scotia (immediately north of Brown's Bank). The whale spent 10 days here.

The overlap of tracks for PTT #843, PTT #840 and PTT #823 through the basins and banks south and east of Nova Scotia (Brown's, Baccaro and Emerald) suggest that these are extremely important areas. We observed numerous SAGs during our visit to these areas. The presence of a pregnant female (PTT #840) in these areas suggests the region is used for more than reproductive activity (SAGs). These areas are also along the 200 m contour where previous studies (CeTAP, 1982; Mate, et al., in prep.) have observed right whales feeding. Studies off Nova Scotia by C. Miller (pers. comm.) show that the concentrations of copepods in this region move from the banks into the deeper basin waters from September through February. This feature of copepod concentration may constitute an important resource for right whales in the fall and winter.

CONCLUSIONS

Satellite telemetry is a highly effective method of tracking right whales even for relatively short periods of time. These studies resulted in the complete re-evaluation of previous hypotheses regarding range, residency time, speeds of travel, dive depths, and surface resting.

Movements and Distribution

Right whales were previously reputed to be slow moving, nearshore animals. Based on our data, we have determined that right whales can travel long distances (3,833 km) over short periods of time (43 days) and can travel up to 500 km from shore into deep (4000+km) water. The fast movement of two males between all known (BOF and Scotian Shelf) breeding areas suggests the Northwest Atlantic population may be a single stock. The movements of a pregnant female through the same areas also suggests these areas may also be important to feeding. The long distance coastal movement of a female and calf surprised us. It is not known whether the female traveled to look for food, train the calf in how and where to find food, or both.

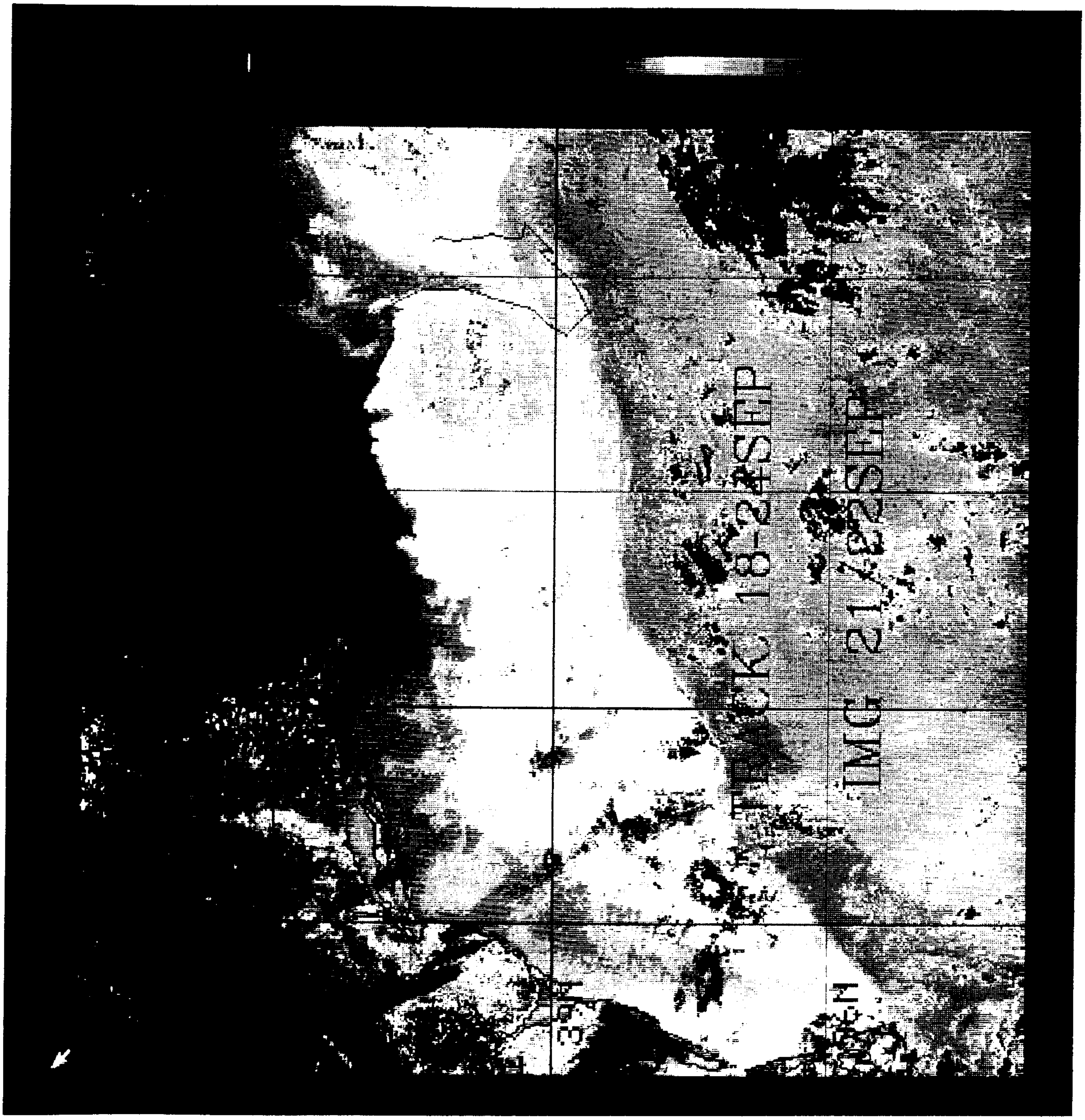
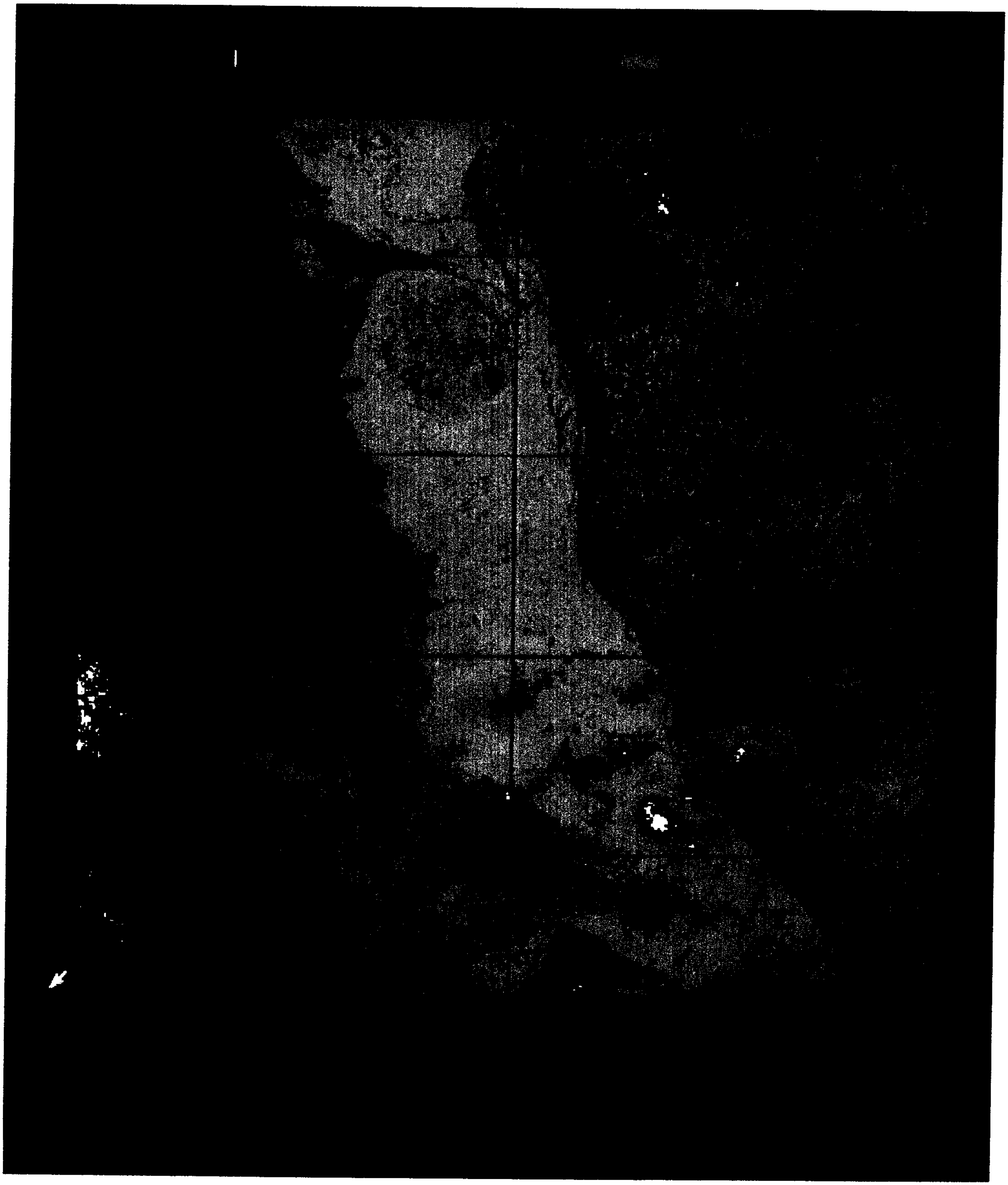


Figure 91. NOAA satellite-monitored sea surface temperatures. This color image is a composite of data collected by the URI/NOAA Remote Sensing Lab on 21 - 22 September 1990 and shows the track of PTT #823 along the eastern edge of a warm core ring north of the Gulf Stream.



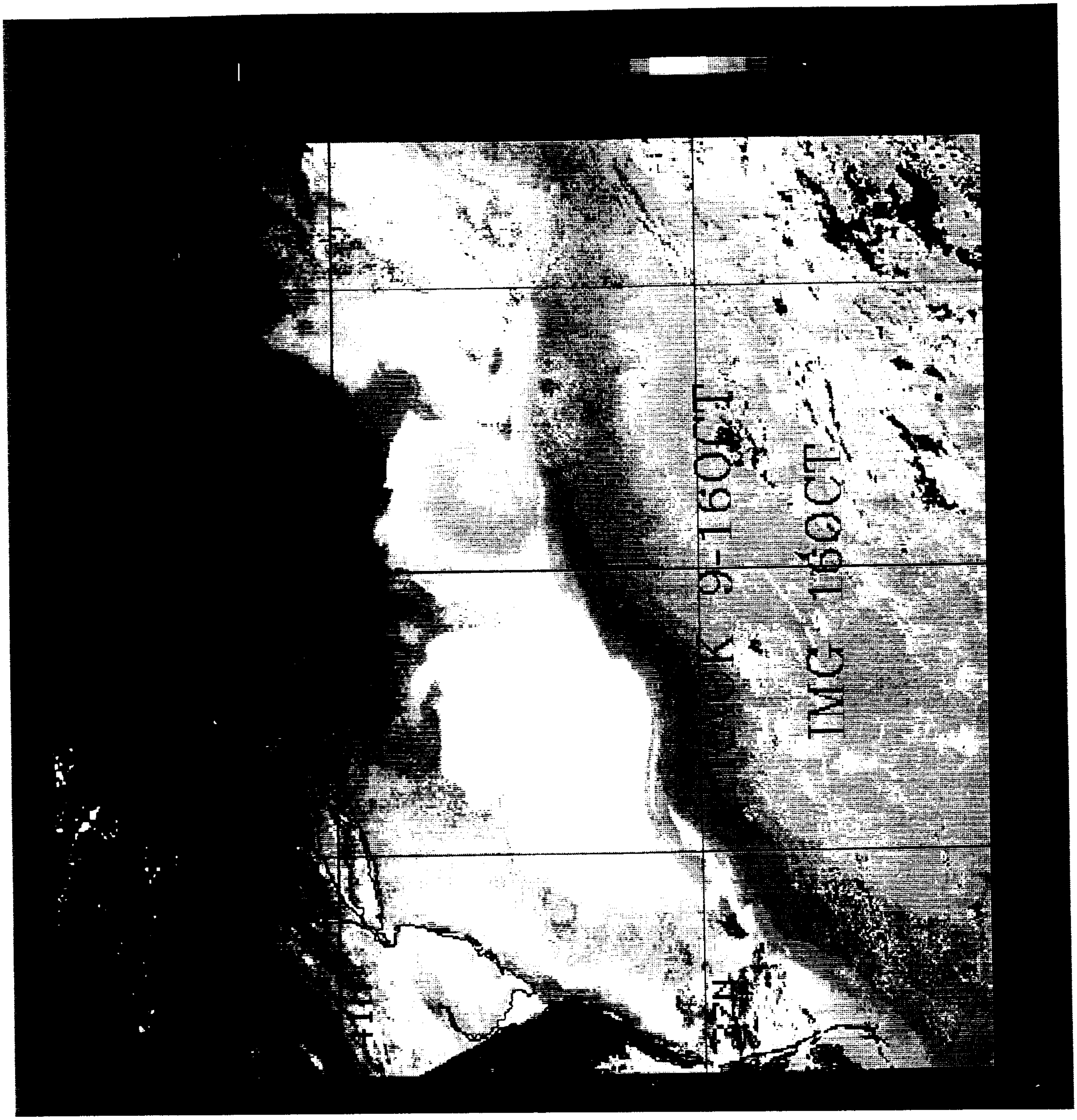
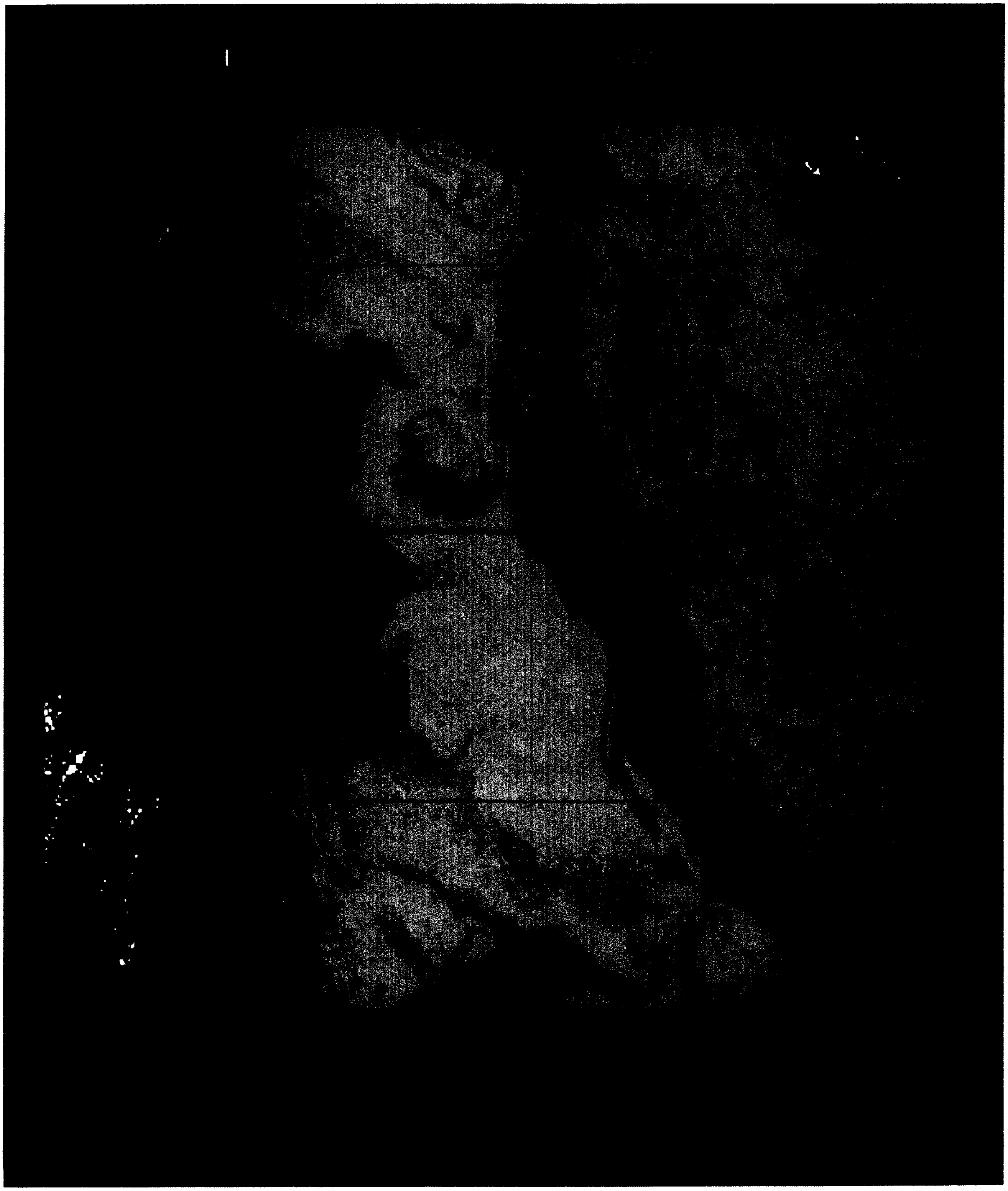


Figure 92. NOAA satellite-monitored sea surface temperatures. This color image is a composite of data collected by the URI/NOAA Remote Sensing Lab on 16 October 1990 and shows the track of PTT #823 in an area of upwelling south of Nova Scotia.



The return of several animals back into the BOF after extensive travel revises former assumptions regarding residency time. Previously, the time between repeat BOF sightings within the same season was considered an estimate of minimum residency time. Now it is obvious that animals can travel widely between such sightings.

Feeding

Because some animals stay in the BOF and others return after extensive travel, the BOF appears to be an important area. We believe part of the importance of the BOF is feeding because: 1) we observed very little breeding activity there; and, 2) we tagged juveniles, females with calves and a pregnant female, none of which would normally have been involved in mating activity.

During our studies, we observed evidence of whales going to the bottom. Some surfaced with mud on their heads in water 200 m deep suggesting bottom feeding. Data from one whale instrumented for dive depths demonstrated dives to or near the bottom routinely. Because copepods are weak diel migrators, prey depth and concentrations are not predictable. Therefore, right whales may routinely examine several hundred meters of the water column to locate their food which may often include the bottom. Their long dive capability also allows them to forage at these reasonable depths. The concentration of whales we observed in the BOF suggests that large tidal changes and associated currents might concentrate diurnal migrants in the deeper channels.

Recent studies on the Scotian Shelf by C. Miller (pers. comm.) show copepods concentrated on the banks in the summer and moving into the basins during the fall. The movements of two males in October and November into the basins east and southeast of Nova Scotia suggest that these may be fall (if not winter) feeding areas.

The concentration of "deep dives" along the 200 m contour east of Jeffreys Ledge occurred in an area of frequent upwelling. Dives in this region were most consistently in the range of 130 m and may thus have been "off the bottom." The significance of the 200 m contour for right whales in our studies is similar to the 100 m contour found by Winn, et al. (1986) and CeTAP (1982) in the Great South Channel. The bank edges used by right whales in our studies adjoin basins which may harbor copepod concentrations, but also often correspond to the continental slope edge dropping off into deep water.

Many of the whale's movements coincided with eddies and thermal features such as fronts, upwellings and warm core rings (WCR). Upwellings usually have higher productivity, and fronts and eddies frequently concentrate prey. We were particularly surprised to see movements along a warm core ring edge far offshore in deep water. We do not know if right whales seek prey in areas of previous success, or recognize oceanographic characteristics where prey would concentrate.

Diving

The only right whale instrumented for depth dove deep routinely. The average dive duration for individual right whales (86 s +/- 48) varied between 54 - 162 s. The number of dives varied from 9.2 to 153/hr. ($\bar{x}$ = 44.6/hr.). The variability in dive habits appears to be real, making simple correction factors for aerial and ship surveys less likely. We believe some of these differences were related to individual variability and environmental circumstances rather than differences in sex, age, or behavior. Whale diving strategies appeared to be most alike when they were swimming at "high" speeds (> 10km/hr.) although they were still not identical. We believe the relationship of average dive duration and number of dives/hour during high speed swimming may approach an optimal aerobic respiratory rate.

Resting

All whales spent time at the surface, but some more than others (range 13-33%). Interestingly, the fastest animal (a female) spent the most time at the surface, with 69% of all transmissions indicating surface resting. In contrast, a male spent less time surface resting when he was traveling between breeding areas than when he settled into one area and was presumably feeding.

Effects of Tagging

The 1989 attachment system was large, heavy, difficult to apply and not very effective. The two-stage projectile sequence did not work well due to drag and turbulence. None of the pole-deployed tags deployed in a completely satisfactory manner although one lasted 22 days and gave excellent dive depth information.

We observed mixed reactions to the tagging process in 1989. None of the tags fully deployed. One whale resumed sleeping almost immediately after tagging while two others actively avoided the boat when we attempted to closely approach for follow-up observations. Overall, 1989 responses were more than would have been expected by a close boat approach. One whale tagged in 1989 was observed in 1990 at close range had a short straight white scar were the tag had been.

The transmitters in 1990 were greatly reduced in size and weight compared to those used in 1989, although they no longer recorded depth data. The 1990 attachment system worked well. The tags were easily applied and caused only **mild reactions** from a few whales. Three whales were approached from 1-4 days after tagging with no more avoidance response than untagged whales. While we did see some mild swelling shortly after tag application on three animals in 1990, this was a normal and anticipated initial response to the process. There appeared to be **no long-term ill affects** from tagging. Calves did not separate from mothers. Some whales did not move from the tagging area. Those whales that moved out of the area also came back into or toward the BOF. The whale with the longest track was observed 16 days after its last transmission and was still with its calf. There was no swelling where the tag had been and only a single circular 6 mm scar. We believe the 1990 tagging was **neither overtly stressful nor a significant health hazard** for right whales. We believe the attachment life is related more to pressure necrosis from rubbing and hydrodynamic drag on the tag than active tissue rejection.

Ship Collisions

Right whale movements varied, but all animals were exposed to areas of heavy ship traffic. All of the whales we tagged were in the deepest water in the BOF which is the shipping channel. "Wart's" travels took her through the Boston and Long Island shipping lanes. Other whales used the 200+m slope edge. This tends to be the "first deep water" sought by large shipping vessels and thus overlaps an often used area of right whales. Prolonged surface resting (especially along the shelf edge) further exposes right whales to a risk of ship collision. In our experience, right whales are not easily disturbed when resting at the surface. Ships travel just off the shelf edge along Nova Scotia which is the shortest route in "deep" water between some U.S. and Canadian ports. Kraus (1990) has documented the scarring of 75% of the right whale population and attributed a portion of these to ship collisions. Based on the movements of tagged right whales into areas of high ship traffic and their surface resting activity, we conclude that injuries from collisions with large ships are likely.

RECOMMENDATIONS

We recommend MMS continue satellite-monitored large whale tracking as the most cost-effective (and in some cases, the only) method of acquiring movement and dive data on numerous wide-ranging whales simultaneously. The following recommendations will help achieve longer lasting and more effective satellite-monitored tags. We have suggested specific subject and geographic areas for right whale and bowhead whale research where this technology can be used to an advantage.

Additional research on **bio-compatible materials** may be helpful in finding a strong material for attachments or a transcutaneous antenna coating less likely to be rejected than stainless steel. The observation of stainless steel attachments bending 40 degrees suggests these materials will need to be supple and have considerable shear strength. The success we have experienced with dorsal fin attachments may be due in part to the use of plastic attachments which have no galvanic potential and therefore may be less irritating.

Decreases in the physical size of the tag have occurred annually for the last several years, and there is the promise of a dramatic size reduction in 1992 at the sacrifice of sensor data. We recommend **further miniaturization** of the tags on the simple basis of reducing hydrodynamic drag and a likely increase in attachment longevity. The determination of whether or not drag is a factor in tag longevity might be accomplished by an experiment which used both "standard" size tags and "miniature" tags on the same species during the same season, even if the smaller tags resulted in **location data alone**. Smaller size (and possibly reduced weight) may also be achieved by "**potting**" (filling air spaces) transmitters with suitable materials to reduce the need for heavy **pressure housings**. This has not been done in the past because the dielectric of the potting material caused the sensitive RF section of the transmitter to become detuned. Telonics has recently achieved potting of both the digital and RF portions of their smallest transmitter. However, the "savings" in weight may be negligible and additional **structural strength** beyond the potting material may be needed for anchoring the attachments. Most of the recent weight savings in transmitters have come from reduced battery requirements due to lower power output or reduced transmission schedules. Additional savings in battery power can be achieved by even better **coordination of transmissions** with the satellite passes.

Because sensor data are prone to error from a variety of sources, we recommend the sensor data include an **error detection**, if not error correction, code. There is also a need for Service Argos to complete its promised work on this issue and reporting the details of all messages, including the times of transmission for duplicate messages.

Our data suggest that temperature plays a significant role in right whale movements and their food gathering. **Temperature monitoring** should be one of the data priorities. We recommend satellite sea surface temperatures and meteorological information be included in future tracking budgets as they are key to interpreting some of the animal's behaviors and movements.

As our previous knowledge of whales has been collected largely from visual observations of surface activity, and much of the animal's behavior occurs below the surface and out of sight, we recommend additional **sensor and microprocessor capabilities** be developed for **pressure, temperature, acoustics and heart rate. Pressure sensors** describe the third dimension of the whale's world and demonstrated its usefulness for right whales in 1989. Dive depths deserve further attention.

Physiological monitoring such as **heart rate** would also be desirable to appreciate the animal's response to potentially adverse stimuli. Whales reduce their heart rate (bradycardia) during diving. Most animals increase their heart rate in response to frightening stimuli. Heart rate is presently monitored for seals with VHF tags by the Sea Mammals Research Unit in the U.K. (M. Fedak, pers. comm.) and has been demonstrated by T. Williams (pers. comm.) on bottlenose dolphins and by K. Brennan and J. Lien (pers. comm.) on large whales with a wire lead system. Further monitoring of the animal's acoustic environment could demonstrate tolerances and sensitivity to ship traffic and seismic events while exploring the animal's own communications.

This is the first large data set of its kind to be analyzed. As a result, we now know a great deal more about the specific movements and round-the-clock dive patterns of right whales than ever before. The amount of satellite-acquired information and additional data from other sources requires a considerable amount of time to verify and correlate. Tagging right whales for two years on a single year's budget has precluded an exhaustive analysis for this report and preparation of peer-reviewed publications. We will request and recommend limited additional funding to correlate existing weather records with this right whale data and prepare these findings for publication. We recommend that **adequate time** is set aside in future studies to accomplish a thorough **evaluation and write up** of the analyzed data.

Additional tagging of right whales would resolve the question of individual variability versus correlated differences between age, sex and reproductive classes. Retagging some of the same individuals would resolve whether they have annual stereotypic patterns. Specific biological questions also remain. It appears from recent genetic studies (M. Brown, pers. comm.) that there are three matrilineal **stocks** of right whales and one does not visit the BOF. One member of this stock has been seen off **Greenland** and in **Cape Cod Bay** (CCB) in the Spring. Because there are small numbers of right whales in CCB in the spring, the chances of tagging an individual that would go to Greenland may be better than in any other location. Other areas which deserve tagging attention include: the **winter calving grounds** off Georgia and Florida to determine the movements of pregnant females and females with calves; the **GSC** in the spring to examine dispersion; and areas south and east of **Nova Scotia** in the fall where we saw considerable right whale activity. The area **east of Halifax** and south to the tip of Nova Scotia was used more by right whales than expected and it would be worthwhile to conduct **aerial surveys** of the region in the early fall to determine whether or not this is a major concentration area. It would also be worth **examining the records of natural history cruise ships** which transit this area in the late summer and early fall to determine if vessel surveys would be worthwhile.

SPECIFIC RECOMMENDATIONS FOR BOWHEAD WHALE TAGGING

We recommend that the exposed portion of the bowhead tag be as small as possible to avoid problems associated with hydrodynamic drag and abrasion of the tag on ice, the bottom and other animals. In the form used during 1990 on right whales, the new split-board ST-6 will reduce the tag diameter from 2" to 1 7/8". The same transmitter can be fitted into a "T-type" configuration (Figure 93), with half as many batteries housed in the vertical (subdermal) attachment portion of the "T". The transmitter would be housed in the 1" diameter horizontal portion of the "T" on the surface of the animal. We recommend trying this new design or the "location only" style in addition to the 1990 right whale-type during the 1991 bowhead whale tagging season. Because of the stronger connective tissue and thicker blubber of bowheads, we believe the new tag shape might be more successful. Less tag is exposed and it provides fewer holes in the animal's skin. We also recommend having an applicator with more power as a "back-up" in the event the crossbow is inadequate. We recommend a gun or air-driven propellent system.

While it is not yet possible to fully implant a "capsule tag," it may only be eighteen months before such applications are feasible. We recommend keeping abreast of these developments. It may also be feasible (according to some veterinarians) to implant a tag in muscle with more security and no more risk of infection than present systems limited to the blubber layer. There would still be a transcutaneous antenna lead. Healing and adhesion might be faster due to increased blood supply. We recommend additional inquiry and experimentation in this area.

While we acknowledge some of the limitations of the present technology, we believe the tremendous amount of information collected from even short periods of successful satellite-monitored tracking have been very worthwhile and cannot be economically duplicated by other techniques. We recommend this research be continued as the most cost-effective means presently available to collect information on the movements and dive patterns of free-ranging whales.

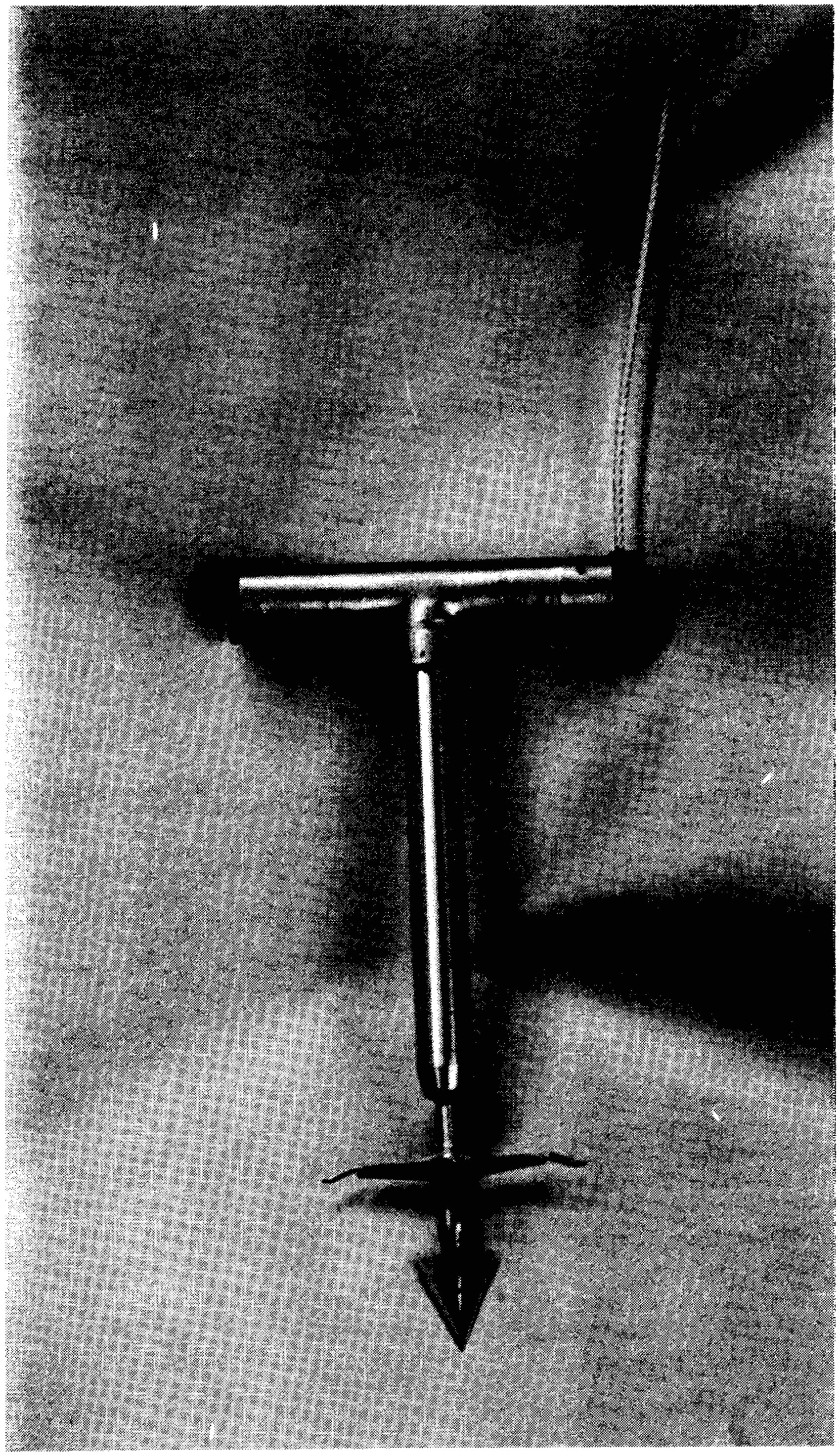


Figure 93. A "T" tag for possible application to bowhead whales in 1992.

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APPENDIX A

ERROR DETECTION:

The data from the pilot whale (1987) transmissions had about a 15% error rate, and it is reasonable to assume that we will continue to have a similar error rate from future transmissions. One method for increasing data reliability is to implement an error detection scheme.

Errors found in the pilot whale transmissions occurred in bursts. "Bursts" are clumps of errors scattered over an otherwise clean transmission. A common scheme for the detection of burst errors is to add a Cyclic Redundancy Check (CRC) code to the transmission.

In concept, the procedures for implementing a CRC code are to:

a) convert the data stream into a polynomial. Each bit position represents a coefficient of a polynomial, for instance:

10101 would be $1x^4 + 0x^3 + 1x^2 + 0x^1 + 1x^0$ and
11010 would be $1x^4 + 1x^3 + 0x^2 + 1x^1 + 0x^0$;

b) multiply the polynomial by x^n, where n = the number of error detection bits being used for the CRC code;

c) divide the result by a special (primitive) polynomial. Primitives are specific to the number of error detection bits being used, for example:

a primitive for 8 bits of error detection is
$1x^7 + 0x^6 + 0x^5 + 0x^4 + 1x^3 + 0x^2 + 0x^1 + 1x^0$
represented by 10001001.

Since there may be more than one applicable primitive, it is important that all parties concerned pre-agree on the primitive to be used;

d) the coefficients of the remainder are the CRC code;

e) append the CRC code to the original data stream and transmit;

f) upon receipt, divide the entire transmission by the primitive. If the new remainder is zero, then there were no errors. If the new remainder is non-zero, then there were errors.

This scheme supposedly works with 100% accuracy for bursts of errors shorter than or equal to the number of bits used for detection. The detectability of errors longer than the number of detection bits is approximately: 94% for 4 bits of detection, and 99.6% for 8 bits of detection.

In practice, the steps for implementing a CRC code are:

1) Append n zero's to the right end of the data stream, where n = number of error detection bits.

2) Divide the extended data stream by a known primitive. Remember that this is modulo-2 POLYNOMIAL division, not straight division. If you have questions refer to the examples.

3) The coefficients of the REMAINDER of the division process are the CRC code. The number of bits in the CRC code must be equal to the number of error detection bits. Pad with leading zero's if necessary.

4) Transmit the original data stream and the appended CRC code.

5) Receive the transmission.

6) Divide (modulo-2 polynomial) the received data stream (including the CRC code) by the known primitive. If the remainder is zero, then there were no errors. If non-zero, an error occurred.

Modulo-2 polynomial division uses modulo-2 addition. Modulo-2 addition can be defined as follows:

```
 0    0    1    1
+0   +1   +0   +1
--   --   --   --
 0    1    1    0
```

This is the "exclusive or" (XOR) function and is equivalent to ordinary addition, except 2 is equal to 0. Note that since $1 + 1 = 0$, then $1 = -1$.

Modulo-2 Polynomial Division:

Example #1: $(1x^4 + 1x^3 + 1x^2 + 0x^1 + 1x^0) \ / \ (1x^1 + 1x^0) =$

$$\begin{array}{lccccccccccl}
 & & & 1x^3 & + & 0x^2 & + & 1x^1 & + & 1x^0 & & \\
\cline{2-10}
1x^1 + 1x^0 \ ) & 1x^4 & + & 1x^3 & + & 1x^2 & + & 0x^1 & + & 1x^0 & & \\
 & 1x^4 & + & 1x^3 & & & & & & & & \\
\cline{2-10}
 & & & & & 1x^2 & + & 0x^1 & + & 1x^0 & & \\
 & & & & & 1x^2 & + & 1x^1 & & & & \\
\cline{6-10}
 & & & & & & & 1x^1 & + & 1x^0 & & \\
 & & & & & & & 1x^1 & + & 1x^0 & & \\
\cline{8-10}
 & & & & & & & & & 0 & & \text{<-- REMAINDER}
\end{array}$$

Example #2: $(1x^4 + 0x^3 + 1x^2 + 0x^1 + 1x^0) \ / \ (1x^1 + 1x^0) =$

$$\begin{array}{lccccccccccl}
 & & & 1x^3 & + & 1x^2 & & & & & & \\
\cline{2-10}
1x^1 + 1x^0 \ ) & 1x^4 & + & 0x^3 & + & 1x^2 & + & 0x^1 & + & 1x^0 & & \\
 & 1x^4 & + & 1x^3 & & & & & & & & \\
\cline{2-10}
 & & & 1x^3 & + & 1x^2 & + & 0x^1 & + & 1x^0 & & \\
 & & & 1x^3 & + & 1x^2 & & & & & & \\
\cline{4-10}
 & & & & & & & & & 1x^0 & & \text{<-- REMAINDER}
\end{array}$$

Modulo-2 polynomial division using coefficients:

Note that these are the same examples as above.

Example #1:

11101 / 11 =

```
                1011
           _________
     11   )  11101
             11
             -----
               101
               11
               ---
                11
                11
                --
                00   <-- REMAINDER
```

Example #2:

10101 / 11 =

```
                1100
           _________
     11   )  10101
             11
             -----
              1101
              11
              ----
                01   <-- REMAINDER
```

WARNING: This is division of polynomials, not straight division of numbers.

Using straight division the above examples work out to:

```
11101 / 11  =  1001 with a remainder of 10
10101 / 11  =  0111 with a remainder of 00
```

or converted to decimal

```
29 / 3  =  9 with a remainder of 2
21 / 3  =  7 with a remainder of 0.
```

These are NOT the results obtained using polynomial division.

Example CRC Code generation (first 3 steps):

Givens:

data stream = 32 bits
error code (n) = 8 bits
known primitive for 8 bits of detection =
1000 1001 $(x^7 + x^3 + 1)$

an example 32 bit data stream =
1010 1110 0011 0010 1011 0000 0110 0001

original data stream
1010 1110 0011 0010 1011 0000 0110 0001

step 1, multilply by x^n (append n zero's)
1010 1110 0011 0010 1011 0000 0110 0001 0000 0000

step 2, divide the polynomials

```
1000 1001  / 1010 1110 0011 0010 1011 0000 0110 0001 0000 0000
             1000 1001
             -----------------------------------------------
                10 0111 0011 0010 1011 0000 0110 0001 0000 0000
                10 0010 01
               ---------------------------------------------
                    101 0111 0010 1011 0000 0110 0001 0000 0000
                    100 0100 1
                   -----------------------------------------
                      1 0011 1010 1011 0000 0110 0001 0000 0000
                      1 0001 001
                     ---------------------------------------
                          10 1000 1011 0000 0110 0001 0000 0000
                          10 0010 01
                         -----------------------------------
                             1010 1111 0000 0110 0001 0000 0000
                             1000 1001
                            --------------------------------
                               10 0110 0000 0110 0001 0000 0000
                               10 0010 01
                              ------------------------------
                                   100 0100 0110 0001 0000 0000
                                   100 0100 1
                                  --------------------------
                                             1110 0001 0000 0000
                                             1000 1001
                                            ----------------
                                              110 1000 0000 0000
                                              100 0100 1
                                             ---------------
                                               10 1100 1000 0000
                                               10 0010 01
                                              --------------
                                                   1110 1100 0000
                                                   1000 1001
```

```
                          --------------
                          110 0101 0000
                          100 0100 1
                          -------------
                           10 0001 1000
                           10 0010 01
                          ------------
REMAINDER                     11 1100
```

step 3, pad with leading zero's

```
                            0011 1100
```

Using hexadecimal notation, the above calculation would be:

AE 32 B0 61 / 89 = ? with a remainder of 3C.

A table of some sample 32 bit data streams and their remainders when divided by the primitive 1000 1001 (89 Hex) (all values are in hexadecimal):

data stream	remainder
00 00 00 01	12
00 00 00 10	32
00 00 01 00	16
00 00 10 00	72
01 D1 E3 96	53
17 24 CD 9E	39
27 48 87 A1	73
2A 3E BE 71	5A
69 53 D9 F1	56
8D 4E 9F 9A	5D
AE 32 B0 61	3C
C1 58 F8 8C	00
C9 4C 1F 55	69
FA F4 17 F9	46

Upon receipt of a transmission, the data stream is once again divided by the primitive. The remainder is compared with the transmitted remainder. If the remainders match, no errors occurred.

References:

Lin, S., An Introduction to Error-Correcting Codes, Prentice-Hall, New Jersey, 1970.

Wakerly, J., Error Detecting Codes, Self-Checking Circuits and Applications, North-Holland, New York, 1978.

Appendix B
1990 PTT format and error detection

INTRO

Since telemetry is prone to transmission errors, data reliability is dependant on the detection and elimination of these errors. In our data, we have observed that these errors tend to occur in bursts (see Michelson and Levesque, 1985 for a description of burst errors). When there is no built in method of error detection, circumstantial methods can be used to identify many errors.

CIRCUMSTANCES

Many factors influence the occurrence of transmissions. Since the radio frequency we use does not travel through water, the tag only transmits when it is out of the water. However, the tag is positioned on a portion of the body that clears the water with each surfacing of the whale.

In order to conserve battery power, transmissions occur only during two hours out of every six.

A further restriction is imposed by the satellite data collection service: no two transmissions from the same transmitter may occur within 40 seconds of each other. This is referred to as "repetition period". The repetition periods for our 1990 transmitters varied from 42 - 52 seconds.

Not all transmissions are received. In addition to all of the above restrictions, a satellite has to be within reception range of the transmitter. In the study area, a satellite comes into reception range about 14 times a day. The satellite then stays in range for only about 10 minutes. These restrictions result in the receipt of an average of 4.8 transmissions per summary period.

The data portion of each 1990 right whale transmission consists of 64 bits containing 6 fields.

field length (bits)	field description
8	temperature (degrees C)
16	duration of dive just previous to transmission (seconds)
16	average dive duration during summary period (seconds)
16	dive count during summary period
2	failsafe flag
6	inter-transmission dive count (itd)
64	

The average dive duration and the dive count are summary data collected over a 6 hour interval (summary period) and transmitted during the following summary period. Throughout a summary period, the transmitted values for these fields do not change. The summary data occupy half of the transmission.

The temperature, dive duration, and inter-transmission dive count reflect conditions at the time of transmission. This data changes with each transmission and is referred to as "discrete" data.

The inter-transmission dive field is a compensation for the repetition period restriction. If the repetition period has not expired when the tag surfaces, no transmission occurs, the inter-transmission dive counter is incremented by one, and the temperature and dive duration are lost.

The failsafe flag is a warning indicator. Normally the field has a value of zero. However, if the sensors indicate that the transmitter has been submerged for longer than 168 hours (7 days), this field transmits a special value. It should be noted that none of the transmitters deployed during 1990 meet the conditions necessary for this field to have a value other than zero. Therefore for this field, any non-zero value is an error.

There is one more useful piece of information provided with the transmission: the time and date the transmission was received by the satellite. While this is not part of the original transmission, the satellite appends it to the transmission and it is part of the record provided by the satellite data collection service.

Example Data Set: transmissions received over 2 summary periods.

	date	time (GMT)	temp (C)	dive dur(S)	itd	dups	fail safe	average dive(S)	# of dives
first	12 Sep 90	23:06:57	20.8	206	1	1	0	40	479
summary	12 Sep 90	23:08:23	20.9	20	1	1	0	40	479
period	12 Sep 90	23:14:24	20.4	176	1	1	0	40	479
second	13 Sep 90	05:25:31	12.7	614	0	1	0	32	843
summary	13 Sep 90	07:02:42	12.2	378	0	1	0	32	843
period	13 Sep 90	07:03:26	12.2	10	2	1	0	32	843
	<- date and time -> of transmission		<---- discrete ---->					<- summary ->	
	<-- appended by --> the satellite		<------- transmitted from the tag ------->						

ERROR DETECTION METHODS:

Summary data:

The duplication of the summary data provides an easy method of error detection. If two or more transmissions occurring in the same summary period have the same value for a summary field, then the value is either correct or exactly the same error burst occurred. The probability of identical error bursts occurring in neighboring transmissions is quite low (less than 0.1%) so duplicate values are assumed to be correct. Any other value is an error. If there are no duplicate values, then the summary field cannot be confirmed and is assumed to be in error.

Additionally, some simple range checking can be performed. Since the minimum duration of a dive is 6 seconds, this is also the minimum value for the average dive duration field. The maximum value for the dive count is 3600:

max dive count = summary period / minimum dive duration

= 21,600 seconds / 6 seconds
= 3600.

Discrete data:

It is more difficult to detect errors in the discrete dive information. However, the following checks can still be performed:

1) Does the failsafe field have a zero value? Since the conditions for a non-zero value of the failsafe field were never attained, any non-zero value in this field is an error.

2) Is the temperature above -40 degrees C? This check is separate from the following temperature check, because transmissions from one of the tags would occasionally report a drop to an extremely low temperature (below -40) and stay at that reading for an extended duration (up to a couple days). During these times, all the other readings would appear normal. Therefore, we concluded that the sensor, rather than the transmission, was faulty.

3) Is the temperature within believable limits (3 - 36 degrees C)?

Examples:

temp	error
-60	faulty sensor
-3	below range limit
50	above range limit
10	no error

4) Is the duration of the dive just previous to the transmission less than a maximum value (45 minutes)?

5) Is the inter-transmission dive count less than the maximum possible for the repetition period? With a minimum dive duration of 6 seconds and a minimum of one second at the surface, the minimum duration for a full dive-surface cycle is 7 seconds. If the repetition period is 42 seconds, a maximum of 6 dives can occur during the repetition period.

6) Is the sum of the previous dive duration and the minimum time necessary inter-transmission dives (7 seconds per inter-transmission dive) less than the duration of the interval between the current and previous transmissions.

Examples:

previous dive duration HH:MM:SS	inter trans dives	calc interval HH:MM:SS	actual interval HH:MM:SS	error
00:50:00	0	0:50:00	1:30:00	actual exceeds maximum
00:02:00	0	0:02:00	0:01:30	calc exceeds actual
00:02:00	2	0:02:14	0:02:10	calc exceeds actual
00:02:00	2	0:02:14	0:02:20	no error

7) If the dive duration is zero, is the inter-transmission dive count zero? A dive duration of zero occurs when the tag is out of the water for the entire repetition period. In this instance, no

inter-transmission dives can occur.

CONCLUSION

Since transmission errors occur in bursts, any error subjects the entire transmission to doubt. Therefore, transmissions with errors are not used in the analysis of discrete data. However, if a faulty temperature sensor is the only error detected in a transmission, the transmission is used for dive duration analysis but not temperature analysis.

Errors do not affect the summary data in such a dramatic manner. A duplicate value within a summary period is the correct value for that period. Therefore, other errors can be ignored for summary data analysis.

----

line	PTT	Date	time(GMT)	pass	temp	last	aveDur	sumDiv	fail	itd	dup	err
01	823	12 Sep 90	23:48:41	21	12.4	112	57798	51148	3	33	1	182
02	823	12 Sep 90	23:50:07	21	12.4	0	140	110	0	0	1	48
03	823	12 Sep 90	23:57:09	21	2.6	418	140	622	0	4	1	18480
04	823	13 Sep 90	05:25:31	22	12.7	614	232	79	0	0	1	0
05	823	13 Sep 90	05:26:14	22	14.7	43008	232	79	0	7	1	4098
06	823	13 Sep 90	07:02:42	23	12.2	378	232	79	0	0	1	0
07	823	13 Sep 90	07:03:26	23	12.2	10	232	79	0	2	1	0
08	823	13 Sep 90	11:59:28	24	13.3	14	168	32881	0	0	1	16
09	823	13 Sep 90	12:04:53	24	13.5	288	168	113	0	0	1	0
10	823	13 Sep 90	12:05:35	24	13.5	12	168	113	0	0	1	0
11	823	14 Sep 90	11:39:27	29	14.1	260	52	388	0	1	1	0
12	823	14 Sep 90	11:40:13	29	13.7	20	52	388	0	1	1	0
13	823	14 Sep 90	11:41:01	29	14.1	20	54	4500	0	9	1	2194
14	823	14 Sep 90	11:47:10	29	13.5	20	8112	743	3	37	1	150
15	823	15 Sep 90	00:44:07	32	20.0	274	48	8594	0	0	1	16
16	823	15 Sep 90	00:45:06	32	13.9	18	48	402	0	2	1	0
17	823	15 Sep 90	06:43:43	33	20.4	22	44	428	0	1	1	8
18	823	15 Sep 90	12:54:44	34	20.0	204	40	33262	0	1	1	16
19	823	15 Sep 90	12:56:54	34	14.5	14	40	494	0	2	1	0
20	823	15 Sep 90	12:58:41	34	20.0	20	40	494	0	1	1	0
21	823	15 Sep 90	12:59:30	34	20.0	22	40	494	0	1	1	0
22	823	15 Sep 90	18:06:57	35	20.8	206	40	479	0	1	1	0
23	823	15 Sep 90	18:08:23	35	14.9	20	40	479	0	1	1	0
24	823	15 Sep 90	18:14:24	35	20.4	176	40	479	0	1	1	0
25	823	15 Sep 90	18:16:20	35	14.9	28	40	479	0	1	1	0
26	823	16 Sep 90	06:28:10	37	25.8	282	40	460	2	1	1	4
27	823	16 Sep 90	06:28:54	37	14.5	14	40	460	0	1	1	0
28	823	16 Sep 90	17:53:42	39	14.7	22	38	489	1	2	1	20
29	823	16 Sep 90	17:55:23	39	14.7	80	38	483	0	1	1	0
30	823	16 Sep 90	17:57:06	39	14.3	78	38	483	0	1	1	0
31	823	16 Sep 90	17:58:52	39	14.3	18	38	483	0	1	1	0
32	823	16 Sep 90	18:00:42	39	14.5	34	38	483	0	1	1	0
33	823	16 Sep 90	18:04:14	39	14.1	156	38	483	0	0	1	0
34	823	16 Sep 90	18:05:02	39	14.1	12	38	483	0	10	1	2050
35	823	16 Sep 90	18:05:46	39	14.1	8	38	33251	0	2	1	16
36	823	17 Sep 90	12:12:24	43	20.0	8	26	530	0	1	1	0
37	823	17 Sep 90	12:13:07	43	20.4	8	26	530	0	1	1	0
38	823	17 Sep 90	12:13:53	43	20.8	8	26	530	0	1	1	0
39	823	17 Sep 90	12:14:37	43	23.8	11564	11564	53970	3	26	1	6294
40	823	17 Sep 90	12:21:14	43	21.7	8	26	530	0	2	1	0

The error codes are:

32768 the first summary period does not cover a full 6 hours.

```
                (this is not checked by the program, it is done by hand)

    temp
       16384    temp less than min_temp                 ( 3 degrees C)
        8192    temp greater than max_temp              (36 degrees C)

    dive duration
        4096    duration exceeds max_duration           (45 min)
        2048    (duration + (7sec * ITD)) exceeds time since previous transmissi

    zero duration dives
        1024    (duration = 0) AND (itd <> 0)

    average dive duration
        512     ave_dur less than min_ave_dur
        256     summary period does not have two matching ave_durs
        128     ave_dur does not match period_ave_dur

    number of dives
        64      sum_dives greater than max_sum_dives
        32      summary cycle does not have two matching sum_dives
        16      sum_dive does not match cycle_sum_dive

    number of transmissions
        8       only one transmission

    failsafe
        4       failsafe set

    Inter Transmission Dives
        2       ITD exceeds max_itd

    Temp sensor failure
        1       temp at 999
```

Each time an error is identified, the code for that error is added to the error

RIGHT WHALE CATALOG

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1135	F	3	2	67	2728.0	8016.0	FL	CALD	1	W/CALF	A
1135	F	29	4	74	4150.0	7011.0	MB	WHOI		W/CALF	A
1135	F	19	8	80	4250.4	6532.6	BB	URI		"STRIPE"	A
1135	F	1	4	81	2748.6	8024.5	FL	AG*		W/CALF1163	A
1135	F	12	6	81	4158.0	7024.0	MB	WHOI		W/CALF1163	A
1135	F	13	8	81	4442.5	6635.0	BOF	NEA/A		"?"	A
1135	F	18	8	81	4442.8	6621.9	BOF	NEA/N		W/CALF1163	A
1135	F	19	8	81	-	-	BOF	COA		W/CALF1163	A
1135	F	2	9	81	4442.8	6625.0	BOF	NEA/A		W/CALF1163 *	A
1135	F	8	9	81	4438.2	6626.4	BOF	NEA/N		W/CALF1163	A
1135	F	18	4	82	4200.8	7009.8	MB	CCS		W/CALF1163	A
1135	F	3	8	82	4445.5	6637.9	BOF	NEA/N		W/CALF1163 *	A
1135	F	4	8	82	4447.5	6637.5	BOF	NEA/S		W/CALF1163	A
1135	F	30	8	82	4445.9	6633.8	BOF	NEA/S		W/CALF1163	A
1135	F	1	9	82	4444.8	6637.9	BOF	NEA/S		W/CALF1163	A
1135	F	11	9	82	4437.6	6631.8	BOF	NEA/N		W/CALF1163	A
1135	F	20	9	82	4443.1	6622.9	BOF	NEA/N		W/CALF1163	A
1135	F	20	9	82	4444.0	6625.0	BOF	NEA/A		W/CALF1163	A
1135	F	5	10	82	4441.0	6619.0	BOF	NEA/A		"?"	A
1135	F	21	2	84	2905.3	8053.6	FL	NEA/A		W/CALF1406 *	A
1135	F	26	3	84	3055.4	8118.4	GA	URI/A		W/CALF1406 *	A
1135	F	28	4	84	4153.8	7016.4	MB	CCS		W/CALF1406	A
1135	F	11	5	84	4200.8	7012.8	MB	CCS		W/CALF1406	A
1135	F	6	8	84	4442.5	6626.2	BOF	NEA/S		W/CALF1406	A
1135	F	17	8	84	4437.0	6627.0	BOF	NEA/S		W/CALF1406 *	A
1135	F	18	8	84	-	-	BOF	NEA/A		W/CALF1406	A
1135	F	18	8	84	4437.0	6627.0	BOF	NEA/J		W/CALF1406	A
1135	F	19	8	84	-	-	BOF	NEA/J		W/CALF1406	A
1135	F	19	8	84	4443.0	6630.0	BOF	NEA/S		W/CALF1406	A
1135	F	22	8	84	4428.2	6631.8	BOF	NEA/N		W/CALF?SAG *	A
1135	F	26	8	84	4437.0	6633.0	BOF	NEA/N		W/CALF1406 *	A
1135	F	27	8	84	4435.9	6625.2	BOF	NEA/N		W/CALF1406	A
1135	F	3	9	84	4436.7	6630.4	BOF	NEA/N		W/CALF1406 *	A
1135	F	10	3	85	4156.6	7013.6	MB	CCS			A
1135	F	11	3	85	4156.4	7014.4	MB	CCS		SKIMFEEDING	A
1135	F	28	3	85	4208.6	7018.8	MB	CCS		SAG	A
1135	F	7	1	87	3016.0	8123.0	FL	NEA/A		W/CALF1706	A
1135	F	15	2	87	2742.0	8022.0	FL	NEA/A		W/CALF1706	A
1135	F	16	2	87	2740.5	8021.7	FL	FV*		W/CALF 1706	A
1135	F	8	4	87	4156.1	7014.3	MB	CCS		W/CALF 1706?	A
1135	F	15	4	87	4200.1	7015.0	MB	CCS		W/CALF 1706	A
1135	F	15	9	87	4436.5	6626.0	BOF	NEA/N		W/CALF 1706	A
1135	F	17	9	87	4434.2	6626.5	BOF	NEA/N		W/CALF 1706	A
1135	F	23	9	87	4435.5	6627.2	BOF	NEA/N		W/CALF 1706	A
1135	F	6	10	87	4438.3	6622.8	BOF	NEA/N		W/CALF1706	A
1135	F	22	8	90	4435.2	6627.2	BOF	NEA/N			A
1135	F	24	8	90	4443.4	6624.6	BOF	NEA/N		SATTAG	A
1135	F	13	10	90	4207.1	7017.9	MB	CCS			A
1135	F	18	11	90	3051.7	8113.6	GA	ACE			A
1135	F	4	8	91	4436.4	6626.5	BOF	NEA/N		W/CALF	A
1135	F	12	8	91	4441.1	6620.2	BOF	NEA/N		W/CALF 2135 *	A

RIGHT WHALE CATALOG

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1135	F	29	8	91	4438.6	6626.1	BOF	NEA/N		W/ CALF 2135	A
1135	F	28	9	91	4438.2	6620.1	BOF	NEA/N		W/ CALF 2135	A
1140	F	21	5	81	4118.1	6903.7	GSC	URI	1	"WART"	U
1140	F	18	8	81	4442.3	6623.4	BOF	NEA/N		MUD	U
1140	F	29	8	81	4432.1	6617.1	BOF	URI			U
1140	F	3	8	82	SEE	BOSTON	BOF	UG		"?"	U
1140	F	4	8	82	4439.1	6634.5	BOF	NEA/S		W/CALF1245	A
1140	F	6	8	82	4434.6	6630.3	BOF	NEA/N		W/CALF1245	A
1140	F	7	8	82	4435.8	6628.9	BOF	NEA/S		W/CALF1245	A
1140	F	7	8	82	4436.1	6628.9	BOF	NEA/N			A
1140	F	12	8	82	4437.9	6627.6	BOF	NEA/S		W/CALF1245 *	A
1140	F	18	8	82	4439.1	6625.3	BOF	NEA/S		W/1245,NUR *	A
1140	F	6	9	82	4439.7	6626.7	BOF	NEA/N			A
1140	F	8	9	82	4439.1	6624.3	BOF	NEA/S		W/CALF1245 *	A
1140	F	11	9	82	4437.7	6628.9	BOF	NEA/N		W/CALF1245	A
1140	F	18	9	82	4440.0	6627.0	BOF	NEA/N		W/CALF1245	A
1140	F	20	9	82	4444.0	6625.0	BOF	NEA/A		W/CALF1245	A
1140	F	13	4	86	4202.4	7015.9	MB	CCS		SAG *	A
1140	F	14	4	86	4203.6	7015.2	MB	CCS		SKIMFEEDING	A
1140	F	8	1	87	3017.0	8123.0	FL	NEA/A		W/CALF1704	A
1140	F	29	1	87	3017.0	8122.0	FL	NEA/V		W/CALF1704	A
1140	F	3	2	87	3002.0	8118.0	FL	NEA/A		W/CALF1704	A
1140	F	14	2	87	3154.1	8048.6	GA	URI/A		W/CALF 1704	A
1140	F	8	4	87	4151.3	7013.3	MB	CCS		W/CALF 1704	A
1140	F	9	4	87	4159.2	7011.3	MB	CCS		W/CALF 1704	A
1140	F	10	4	87	4205.0	7016.5	MB	CCS		W/CALF 1704	A
1140	F	11	4	87	4208.2	7020.7	MB	CCS		W/CALF 1704	A
1140	F	7	6	87	4124.7	6851.1	GSC	URI		W/CALF 1704	A
1140	F	11	9	87	4444.5	6624.0	BOF	NEA/N		W/CALF 1704	A
1140	F	2	10	87	4440.3	6627.8	BOF	NEA/N		W/CALF 1704	A
1140	F	7	10	87	4437.0	6638.0	BOF	NEA/S		ALONE	A
1140	F	28	5	88	4113.8	6859.6	GSC	URI/V			A
1140	F	11	1	90	3038.3	8111.9	FL	NEA/A			A
1140	F	6	5	90	4158.7	7016.1	MB	CCS		W/CALF 2040	A
1140	F	15	8	90	4436.2	6627.6	BOF	NEA/N		W/ CALF 2040	A
1140	F	22	8	90	4438.7	6629.9	BOF	NEA/N		SAG, W/CALF 2040	A
1140	F	24	8	90	4443.4	6624.2	BOF	NEA/N		SATTAG,W/CALF 2040	A
1140	F	0	9	90	OLD SCA	NTUM	JL	NHSC		W/CALF 2040	A
1140	F	10	9	90	4217.3	7016.8	MB	CCS		W/CALF 2040	A
1140	F	10	9	90	4215.0	7019.0	MB	PMMRC		W/CALF 2040	A
1140	F	21	10	90	BRIER	ISLAND	BOF	BIOS		W/CALF 2040	A
1146	M	25	10	77	4230.0	7000.0	MB	ORES	1	"VAN HALEN"	U
1146	M	19	8	80	4250.4	6532.6	BB	URI			U
1146	M	19	5	81	ASK	URI	GSC	URI/A		#7002	U
1146	M	26	8	81	4440.6	6626.9	BOF	NEA/N		LG SAG	U
1146	M	2	9	81	4455.1	6648.4	BOF	NEA/N			U
1146	M	2	9	81	4455.1	6648.4	BOF	NEA/A		SAG *	U
1146	M	10	9	81	CHECK	CHART	BOF	UG			U
1146	M	22	9	81	4443.3	6618.3	BOF	NEA/N		SAG	U
1146	M	23	4	83	4208.3	7021.3	MB	CCS			U

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1146	M	27	4	83	4200.3	7018.3	MB	CCS			U
1146	M	28	4	83	4200.8	7017.9	MB	CCS		SAG *	U
1146	M	28	4	83	4201.0	7019.0	MB	WHOI			U
1146	M	28	4	83	RACE	POINT	MB	FW*		SAG	U
1146	M	30	4	83	4201.5	7016.1	MB	CCS		SAG *	U
1146	M	1	5	83	4201.0	7015.6	MB	CCS			U
1146	M	6	3	84	4155.5	7018.4	MB	CCS		SKIMFEEDING?	U
1146	M	28	3	84	4200.2	7013.4	MB	CCS		SKIMFEEDING	U
1146	M	1	4	84	4155.3	7011.7	MB	CCS		SKIMFEEDING	U
1146	M	2	4	84	4200.6	7008.8	MB	CCS		W/La's,SKMFDG*	U
1146	M	5	8	84	4259.9	6511.1	BB	NEA/T		SAG	U
1146	M	22	8	84	4427.8	6631.6	BOF	NEA/N		SAG	U
1146	M	26	8	84	4429.0	6629.0	BOF	NEA/S			U
1146	M	26	8	84	4437.0	6630.0	BOF	NEA/N		SAG	U
1146	M	27	8	84	4436.7	6632.2	BOF	NEA/N		SAG	U
1146	M	7	10	84	4442.5	6635.8	BOF	NEA/N		*	U
1146	M	25	3	87	4152.6	7010.5	MB	CCS			A
1146	M	28	9	87	4433.0	6624.7	BOF	NEA/N			A
1146	M	8	3	88	4152.0	7012.9	MB	CCS		SKIMFEEDING	A
1146	M	15	5	88	4119.3	6858.8	GSC	URI/A			A
1146	M	2	9	88	4251.2	6534.3	BB	NEA/7		SAG	A
1146	M	22	3	89	4155.5	7010.4	MB	CCS			A
1146	M	25	3	89	4150.7	7013.7	MB	CCS		SAG	A
1146	M	26	4	89	4153.4	6824.5	GSC	URI/A		SAG	A
1146	M	23	8	89	4203.3	6507.4	BB	NEA/7		SAG	A
1146	M	27	8	89	4259.1	6502.6	BB	NEA/7			A
1146	M	1	9	89	4251.3	6516.7	BB	NEA/7		SAG	A
1146	M	12	9	89	4257.7	6508.2	BB	NEA/7		*	A
1146	M	15	10	89	4439.7	6627.8	BOF	NEA/N		SATTAG. SAG *	A
1152	M	27	8	81	4459.9	6643.9	BOF	NEA/N	1	"NECKLACE"	U
1152	M	2	9	81	4458.9	6646.6	BOF	NEA/N			U
1152	M	3	9	81	4456.0	6647.4	BOF	NEA/N			U
1152	M	6	9	81	4458.0	6645.0	BOF	NEA/N			U
1152	M	11	9	81	4500.6	6646.7	BOF	NEA/N			U
1152	M	12	9	81	4500.1	6647.9	BOF	NEA/N			U
1152	M	24	7	82	4434.0	6632.0	BOF	NEA/N			U
1152	M	27	7	82	4443.3	6619.9	BOF	NEA/N			U
1152	M	3	8	82	4441.4	6633.8	BOF	NEA/S			U
1152	M	6	8	82	4437.5	6626.9	BOF	NEA/N			U
1152	M	21	8	82	4438.0	6624.6	BOF	NEA/N			U
1152	M	8	9	82	4440.9	6622.7	BOF	NEA/S			U
1152	M	20	9	82	4442.8	6624.9	BOF	NEA/N		SAG	U
1152	M	27	4	83	4127.8	6913.0	GSC	ORES		SAG	U
1152	M	23	10	83	4253.0	7015.0	JL	NEWW			U
1152	M	22	9	84	4254.8	7012.9	JL	NEWW			U
1152	M	29	9	84	4255.2	7015.6	JL	BP*			U
1152	M	9	5	85	4137.5	6920.1	GSC	URI/A			U
1152	M	22	8	85	4440.0	6635.0	BOF	NEA/S			U
1152	M	23	8	85	4426.8	6634.5	BOF	NEA/N			U
1152	M	1	2	86	4155.5	7011.2	MB	CCS		POS. SAG *	U
1152	M	7	7	87	4158.6	6852.1	GSC	URI			U

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1152	M	30	8	87	4439.2	6624.9	BOF	NEA/D		SAG	U
1152	M	11	9	87	4442.2	6624.0	BOF	NEA/N			U
1152	M	12	9	87	4441.6	6621.6	BOF	NEA/N		SAG W/ 1703	U
1152	M	13	9	87	4436.6	6628.0	BOF	NEA/N		SAG	U
1152	M	15	9	87	4436.8	6625.6	BOF	NEA/N		SAG	U
1152	M	27	5	88	4121.3	6900.1	GSC	URI/V			U
1152	M	20	8	88	4437.8	6629.6	BOF	NEA/N			U
1152	M	23	8	88	SEE LOR	AN	BOF	JG*			U
1152	M	23	8	88	4433.2	6631.8	BOF	NEA/N			U
1152	M	20	5	89	4142.6	6841.4	GSC	URI/V			U
1152	M	3	6	89	4131.6	6843.9	GSC	URI/V			U
1152	M	21	7	89	CONVERT	LORAN	MB	CRU			U
1152	M	21	7	89	CONVERT	LORAN	MB	NHSC			U
1152	M	21	9	89	4435.3	6620.6	BOF	NEA/N		SAG	U
1152	M	21	9	89	4439.6	6621.5	BOF	CESSNA		SAG	U
1152	M	22	8	90	4438.8	6629.9	BOF	NEA/N		SAG *	A
1152	M	24	8	90	4443.0	6623.6	BOF	NEA/N		SATTAG	A
1243	F	7	8	82	4441.0	6631.0	BOF	NEA/N	1	"?"	0
1243	F	7	8	82	4447.6	6632.2	BOF	NEA/S		CALF OF 1242	0
1243	F	22	8	82	4443.4	6617.7	BOF	NEA		CALF OF 1242	0
1243	F	4	8	84	4255.3	6525.3	BB	NEA/T		SAG	2
1243	F	7	10	84	4438.3	6630.5	BOF	NEA/N			2
1243	F	11	6	87	4122.6	6838.8	GSC	URI/V		*	5
1243	F	5	5	88	4135.0	6927.9	GSC	URI/A		SAG	6
1243	F	9	5	88	4134.1	6924.4	GSC	URI/A			6
1243	F	15	5	88	4124.2	6914.2	GSC	URI/A			6
1243	F	11	2	91	3020.5	8119.3	FL	NEA/S		W/ SCARPROP CALF	9
1243	F	16	2	91	3049.2	8122.5	FL	NEA/A		W/ CALF 2143	9
1243	F	17	2	91	3032.1	8117.2	FL	ACE		W/CALF,PROP SCARS	9
1243	F	9	8	91	4437.5	6624.2	BOF	NEA/N		W/CALF *	9
1243	F	25	8	91	4437.0	6633.4	BOF	NEA/N		W/CALF 2143	9
1243	F	2	9	91	4440.0	6627.1	BOF	NEA/N		W/ CALF 2143	9
1243	F	22	9	91	4435.1	6626.8	BOF	NEA/N		W/ CALF 2143	9
1243	F	27	9	91	4438.6	6622.7	BOF	NEA/N		SATTAG W/ CALF2143	9
1406	F	21	2	84	2905.3	8050.3	FL	NEA/A	1	CALF OF 1135 *	0
1406	F	26	3	84	3055.4	8118.4	GA	URI/A		CALF OF 1135 *	0
1406	F	28	4	84	4153.8	7016.4	MB	CCS		CALF OF 1135	0
1406	F	11	5	84	4200.8	7012.8	MB	CCS		CALFOF1135 NUR	0
1406	F	6	8	84	4442.5	6626.2	BOF	NEA/S		CALF OF 1135	0
1406	F	17	8	84	4438.0	6625.0	BOF	NEA/S		CALF OF 1135	0
1406	F	18	8	84	-	-	BOF	NEA/A		CALF OF 1135	0
1406	F	18	8	84	4437.0	6627.0	BOF	NEA/J		CALF OF 1135	0
1406	F	19	8	84	-	-	BOF	NEA/J		CALF OF 1135	0
1406	F	19	8	84	4436.4	6631.9	BOF	NEA/N		CALF OF 1135	0
1406	F	19	8	84	4443.0	6630.0	BOF	NEA/S		CALF OF 1135	0
1406	F	26	8	84	4437.0	6633.0	BOF	NEA/N		CALFOF1135 *	0
1406	F	27	8	84	4435.9	6625.2	BOF	NEA/N		CALF OF 1135	0
1406	F	3	9	84	4436.7	6630.4	BOF	NEA/N		CALFOF1135 *	0
1406	F	9	3	85	4151.8	7013.8	MB	CCS		*	1
1406	F	2	5	85	4347.7	6925.8	ME	USCG		LOBSTERGEAR*	1

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1406	F	10	8	85	4434.3	6628.3	BOF	NEA/N			1
1406	F	13	8	85	4436.1	6633.0	BOF	NEA/N			1
1406	F	18	8	85	4436.9	6627.4	BOF	NEA/N		*	1
1406	F	30	8	85	4435.2	6630.4	BOF	NEA/N			1
1406	F	18	2	88	4154.7	7012.9	MB	CCS			4
1406	F	26	2	88	4159.2	7014.1	MB	CCS			4
1406	F	19	8	88	4248.2	6521.1	BB	NEA/7		SAG	4
1406	F	18	8	89	4439.5	6623.0	BOF	NEA/N			5
1406	F	14	9	89	4434.2	6630.2	BOF	NEA/N		SAG *	5
1406	F	15	10	89	4439.3	6628.3	BOF	NEA/N		SAG	5
1406	F	14	11	89	3341.3	7825.0	SC	NEA/A		W/ 1157	5
1406	F	22	9	91	4436.8	6626.7	BOF	NEA/N			7
1406	F	5	10	91	4440.0	6624.1	BOF	NEA/N		SATTAG DARTED	7
1421	M	27	5	81	4116.0	6903.0	GSC	URI	1	"WILLIE"	U
1421	M	10	8	83	4257.6	6517.0	BB	NEA/A		SAG	U
1421	M	4	9	84	4358.0	6807.0	MDR	COA			U
1421	M	17	9	84	-	-	BOF	NEA/S			U
1421	M	13	10	84	4441.4	6632.5	BOF	NEA/N			U
1421	M	20	3	85	4159.7	7009.6	MB	CCS		SAG	U
1421	M	22	3	85	4152.3	7014.6	MB	CCS			U
1421	M	23	5	85	4126.2	6917.1	GSC	URI/A			U
1421	M	8	2	86	4154.4	7014.9	MB	CCS		SAG	U
1421	M	23	8	86	4256.2	6514.1	BB	NEA/M			U
1421	M	22	9	86	4444.0	6623.7	BOF	NEA/N		SAG*	U
1421	M	16	10	86	4442.4	6628.0	BOF	NEA/N		SAG	U
1421	M	28	8	87	4253.0	6514.0	BB	SFA			U
1421	M	17	2	88	4152.1	7022.9	MB	CCS			U
1421	M	18	2	88	4155.0	7012.8	MB	CCS			U
1421	M	19	2	88	4155.7	7013.5	MB	CCS			U
1421	M	31	8	88	4248.7	6531.7	BB	NEA/7		SAG	U
1421	M	25	9	89	4436.3	6626.3	BOF	NEA/N		SAG	U
1421	M	12	9	90	4431.8	6632.2	BOF	NEA/N		SATTAG, MUD	U
1608	f	17	2	86	2809.4	8033.5	FL	NEA/A	1	CALF OF 1163	0
1608	f	21	2	86	NO LOCA	TION	FL	SEAWLD		CALF OF 1163	0
1608	f	19	6	86	4211.5	7008.7	MB	CCS		CALF OF 1163*	0
1608	f	29	8	86	4215.8	7013.1	MB	CCS		CALF OF 1163*	0
1608	f	31	8	86	4203.7	7020.7	MB	CCS		CALF OF 1163	0
1608	f	0	9	86	-	-	MB	FW*		"MORSE"	0
1608	f	4	9	86	4205.3	7024.3	MB	CCS		CALF OF 1163	0
1608	f	6	9	86	4208.1	7024.7	MB	CCS		CALF OF 1163	0
1608	f	9	9	86	4209.3	7018.2	MB	CCS		CALF ALONE	0
1608	f	19	9	86	4213.1	7026.0	MB	CCS		CALFOF1163*	0
1608	f	20	9	86	4202.2	7018.2	MB	CCS		CALF ALONE*	0
1608	f	25	9	86	4201.0	7013.7	MB	CCS		CALFOF1163	0
1608	f	27	9	86	4200.8	7010.2	MB	CCS		CALF OF 1163	0
1608	f	1	10	86	4200.7	7018.1	MB	CCS		ALONE	0
1608	f	2	10	86	4200.8	7010.9	MB	CCS		CALF OF 1163	0
1608	f	3	10	86	4200.5	7012.1	MB	CCS		ALONE	0
1608	f	4	10	86	4201.0	7014.9	MB	CCS		ALONE	0
1608	f	8	10	86	4209.2	7023.8	MB	CCS		CALF OF 1163	0
1608	f	11	10	86	4208.6	7021.6	MB	CCS		CALF OF 1163	0

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1608	f	12	10	86			MB	URI/V		CALF OF 1163	0
1608	f	12	10	86	4201.1	7013.3	MB	CCS		CALF OF 1163	0
1608	f	13	10	86	4201.1	7013.3	MB	CCS		ALONE?	0
1608	f	15	10	86	4201.8	7016.5	MB	CCS		CALF OF 1163	0
1608	f	16	10	86			MB	DW*		W/1622	0
1608	f	18	10	86	4200.2	7011.3	MB	CCS		CALF OF 1163	0
1608	f	19	10	86	-	-	MB	URI/V		?	0
1608	f	19	10	86	4200.7	7011.6	MB	CCS		CALF OF 1163	0
1608	f	20	10	86	4206.0	7019.6	MB	CCS		CALF OF 1163	0
1608	f	21	10	86	4204.1	7019.3	MB	CCS		ALONE	0
1608	f	25	10	86	4204.1	7020.7	MB	NEA/N		ALONE	0
1608	f	25	10	86	4204.2	7021.4	MB	CCS		ALONE?	0
1608	f	26	5	87	4128.4	6933.1	GSC	URI/A			1
1608	f	21	8	87	4205.5	7015.8	MB	CCS			1
1608	f	26	8	87	4234.2	7027.4	MB	CRU			1
1608	f	28	8	87	4236.7	7024.9	MB	CRU			1
1608	f	30	8	87	4202.8	7011.5	MB	CCS			1
1608	f	1	9	87	4205.6	7016.6	MB	CCS			1
1608	f	10	9	87	4201.4	7013.5	MB	CCS			1
1608	f	14	9	87	4202.2	7016.1	MB	CCS			1
1608	f	15	9	87	4204.1	7015.9	MB	CCS		FEEDING	1
1608	f	16	9	87	4208.1	7010.1	MB	CCS			1
1608	f	11	8	89	4439.5	6627.9	BOF	NEA/N		MUD	3
1608	f	13	9	89	4430.0	6626.8	BOF	NEA/N			3
1608	f	25	9	89	4436.8	6625.6	BOF	NEA/N		DARTED	3
1608	f	1	10	89	4438.6	6628.1	BOF	NEA/N			3
1608	f	15	10	89	4435.4	6634.4	BOF	NEA/N		MUD	3
1608	f	16	8	90	4441.8	6627.2	BOF	NEA/N		*	4
1608	f	21	8	90	4432.8	6631.4	BOF	NEA/N			4
1608	f	25	8	90	4443.0	6622.6	BOF	NEA/N			4
1608	f	31	8	90	4433.7	6631.2	BOF	NEA/N			4
1608	f	1	9	90	4436.3	6631.8	BOF	NEA/N			4
1608	f	9	8	91	4437.6	6623.8	BOF	NEA/N			5
1608	f	12	8	91	4440.6	6621.2	BOF	NEA/N		SAG	5
1608	f	22	9	91	4436.0	6627.2	BOF	NEA/N		MUD	5
1608	F	28	9	91	4437.4	6620.0	BOF	NEA/N		SATTAG	5
1629	F	23	8	86	4256.2	6514.1	BB	NEA/M	1	"IPANEMA"	U
1629	F	7	5	87	4137.9	6832.4	GSC	URI/A		SAG	U
1629	F	29	8	89	4255.7	6507.4	BB	CESSNA		SAG	U
1629	F	4	9	89	4253.0	6519.9	BB	NEA/7		SAG	U
1629	F	11	1	90	3038.3	8111.9	FL	NEA/A		W/ 1140	U
1629	F	15	8	90	4435.9	6627.6	BOF	NEA/N		W/CALF 2029	A
1629	F	20	8	90	4439.1	6627.2	BOF	NEA/N		* W/CALF DARTED	A
1629	F	22	8	90	4438.2	6633.2	BOF	NEA/N		MUD,DARTED,W/CALF	A
1629	F	25	8	90	4441.2	6623.8	BOF	NEA/N		ALONE	A
1629	F	26	8	90	4442.6	6624.8	BOF	NEA/N		SATTAG,W/CALF 2029	A
1629	F	30	8	90	4434.9	6629.7	BOF	NEA/N			A
1629	F	31	8	90	4434.4	6632.2	BOF	NEA/N		ALONE	A
1629	F	1	9	90	4434.1	6632.1	BOF	NEA/N		W/ CALF 2029	A
1941	F	10	8	89	4456.4	6626.7	BOF	NEA/N		DARTED *	0

RIGHT WHALE CATALOG

NEA#	SEX	DAY	MON	YEAR	LATD	LONG	AREA	OBS	ID	COMMENTS	AGE
1941	F	5	9	89	4442.8	6624.0	BOF	NEA/N		CALF OF 1241	0
1941	F	13	9	89	4431.0	6626.4	BOF	NEA/N		ALONE	0
1941	F	14	9	89	4433.1	6630.6	BOF	NEA/N		CALF OF 1241	0
1941	F	16	8	90	4437.1	6628.3	BOF	NEA/N			1
1941	F	26	8	90	4442.0	6625.5	BOF	NEA/N		SATTAG	1
1941	F	1	9	90	4436.0	6632.0	BOF	NEA/N		*	1
1981		23	8	89	4438.9	6627.6	BOF	NEA/N		CALF OF 1281	0
1981		14	9	89	4437.2	6628.1	BOF	NEA/N		CALF OF 1281	0
1981		1	10	89	4444.1	6633.0	BOF	NEA/N		CALF OF 1281	0
1981		15	8	90	4436.1	6627.9	BOF	NEA/N			1
1981		16	8	90	4439.6	6625.3	BOF	NEA/N			1
1981		24	8	90	4444.3	6624.6	BOF	NEA/N			1
1981		25	8	90	4442.2	6623.5	BOF	NEA/N		SATTAG	1
1981		27	8	90	4440.0	6627.3	BOF	NEA/N		* SAG W/ 2018	1
1981		30	8	90	4434.8	6629.7	BOF	NEA/N			1
1981		31	8	90	4436.1	6631.4	BOF	NEA/N			1
1981		1	9	90	4436.4	6632.0	BOF	NEA/N		*	1