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Using Satellite Telemetry to Study the Ecology and Behavior of Antarctic Seals

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The development of miniaturized electronic instruments capable of communicating with satellites has opened exciting new opportunities for studying the ecology of free-ranging seals. Antarctic pack ice seals are particularly well-suited for this application because they are large enough to carry satellite-linked transmitters, they routinely haul out onto ice floes for extended periods allowing data transmission, and they are relatively easy to capture and restrain for instrument deployment. One system presently being used by marine ecologists is Argos, which is carried aboard the NOAA polar-orbiting satellites. Important considerations in using satellite-linked instruments to study seals include: 1) the longevity of the attachment method holding the instruments on the seals, 2) the reliability of the telemetry hardware, 3) the extent to which data may be corrupted during transmission via satellite, and 4) the amount of data that can be relayed to a satellite within a finite period of time. The present study describes the results of early efforts to deploy Argos-linked instruments on 20 crabeater seals (*Lobodon carcinophagus*) and 6 Weddell seals (*Leptonychotes weddellii*) near the Antarctic Peninsula during the austral summer. Transmissions of location information were received for as long as 150 and 84 days, respectively, from instruments deployed on crabeater and Weddell seals, indicating that the attachment method was successful. To test the reliability of data transmission, two seals equipped with instruments were recaptured approximately 5 days after initial deployment and data that had been collected and stored in the instruments' memories were retrieved manually via a link to a portable computer; the seals were then released. Over the subsequent six weeks, the collected data were transmitted to and relayed via the Argos satellite system. A comparison of the two data sets (manually-retrieved vs satellite-relayed) indicated that the accuracy of data relayed via the Argos system is high; however, there are problems with relaying large amounts of sequential data using a transmitter attached to a seal that may not always be in an optimum position for good transmission (i.e., on the ice in clear sight of a satellite). The majority of collected data was transmitted and relayed error-free. Lost data tended to be in large blocks rather than scattered throughout the data set. These results have important implications for improving data transmission in future seal studies by utilizing data summaries, data compaction, and multiple transmissions of data files.

Key words: satellite telemetry, ecology, behavior, Antarctic seals

INTRODUCTION

The development of miniaturized electronic instruments capable of communicating with satellites has opened exciting new opportunities for studying the ecology of free-ranging seals. Antarctic pack ice seals are particularly well-suited for this application because they are large enough to carry sophisticated satellite-linked transmitters, they routinely haul out onto ice floes for extended periods allowing data transmission, and they are relatively easy to capture and restrain for instrument deployment. Satellite telemetry can be a powerful tool to investigate seals' seasonal movements and habitat use, diving and foraging behavior, haulout patterns, and time budgets.

One system presently being used by marine ecologists is Argos, which is carried aboard the NOAA polar-orbiting satellites. Important considerations in using satellite-linked instruments to study seals include: 1) the longevity of the attachment method holding the instruments on the seals, 2) the reliability of the telemetry hardware, 3) the extent to which data may be corrupted during transmission via satellite, and 4) the amount of data that can be relayed to a satellite within a finite period of time. The present study describes the results of some of the first attempts to deploy Argos-linked instruments on crabeater seals (*Lobodon carcinophagus*) and Weddell seals (*Leptonychotes weddellii*). Although previous researchers (Shaughnessy, 1990; Matsuki and Testa, 1991) reported initiating studies using satellite telemetry on these species, this paper presents the first detailed results of such work, along with an evaluation of the feasibility of using the Argos satellite system for investigations of Antarctic seals.

MATERIALS AND METHODS

Two types of satellite-linked instrument packs were designed and deployed on seals in this study. The first type focused on seals' locations and seasonal movements. It had microprocessor-controlled timing circuitry, a seawater conductivity switch (to indicate haulout), and an Argos platform terminal transmitter (PTT) made by Telonics (Mesa, AZ, USA)[1]. These units were programmed to broadcast for up to 6 h every 24 h, when the seal was hauled out on the sea ice.

The second type of instrument pack was designed to collect and transmit data (e.g., heart function in relation to dive depth). In addition to the location packs' components, these instruments were fitted with EKG leads to determine a seal's heart rate and pressure sensors to monitor depth during diving. After a brief delay period following deployment, data were sampled every 10 s until the 32 kilobyte random-access-memory (RAM) was filled, a process that took 28 h. Thereafter, the packs started to transmit their collected data to the Argos system in 32 byte messages. Each instrument was configured to emulate 6 independent PTTs (to increase the number of messages that could be sent to the satellite during a limited period), and messages were transmitted at 30 s intervals whenever the seal hauled out.

Both types of instrument packs were housed in aluminum pressure cases designed and tested to withstand hydrostatic pressure at depths of over 500 m (for a photo of these units, see Figure 5.7 in Bengtson, 1993). The PTTs were powered by 3 lithium "D" cells, and the microprocessor-controlled circuitry by 2 lithium "C" cells. A 20 cm flexible transmitter antenna projected out of the rear of the housing at a 45 degree angle. The housings had cast rubber bases into which nylon netting had been set to facilitate attachment to the seals. Each unit measured 21 x 13 x 7 cm and weighed 2.8 kg.

During the 1985/86 austral summer, 18 location packs were deployed in 2 areas along the Antarctic Peninsula: 6 on crabeater seals near Antarctic Sound (63°20' S, 56°48' W) during early February and 6 each on both crabeater and Weddell seals in Marguerite Bay (69° S, 68°45′ W) during late February and early March. During the next summer in December, 1986, data packs were attached to 8 crabeater seals near Seymour Island, south of Antarctic Sound (64°3′ S, 56°40′ W). These seals were also fitted with small VHF radio transmitters (Advanced Telemetry Systems, Isanti, MN, USA) to allow relocation.

To attach these instruments, seals on ice floes were immobilized by dart with ketamine hydrochloride (approximately 1.7 mg/kg body mass) and physically restrained as needed. To maintain a light anesthesia, additional ketamine (approximately 0.25 mg/kg per 15 min) was administered intravenously (extradural vein) while the packs were being attached and the epoxy allowed to set. Instrument packs were attached to the seals' dorsal pelage using a cyanoacrylic adhesive (Locktite 420 "super glue") and quick-setting resin epoxy (Devcon EK-40). Seals were released once the effects of the drug had worn off.

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

Table 1. Locations and movements of Crabeater and Weddell seals obtained using the Argos system (C, Crabeater seals; W, Weddell seals)

Seal No.	Total transmission period (days)	Total number of locations	Mean number of days per location	Mean distance between locations (km/day)
C 9900	44	27	1.6	24.1
C 9905	95	12	5.4	11.8
C 9911	150	22	6.8	14.6
C 9912	95	30	3.2	7.7
C 9913	8	3	2.7	45.1
C 9916	135	47	2.9	9.2
C 9917	104	13	8.0	9.4
C 9920	39	4	9.8	23.2
Crabeater Seal Means	83.7	19.8	5.1	18.1
W 9906	42	22	1.9	4.8
W 9907	26	8	3.2	4.4
W 9910	84	8	10.5	2.2
Weddell Seal Means	50.7	12.7	5.2	3.8

For those seals fitted with location packs, seal locations were calculated by Service Argos, Inc. (Landover, MD, USA) over the subsequent months using a doppler-shift algorithm. Cases in which multiple locations were received in a single day were averaged together by calculating a central point if the separate locations were less than 2 h or 2 km apart.

To test the reliability of data transmitted to and relayed via the Argos system, 2 of the seals equipped with data packs were relocated using a radio direction finder and recaptured between 3 and 5 days after initial deployment. Both packs had filled their memories with diving data and were transmitting messages to the Argos system. Data that had been collected and stored in the instruments' memories were retrieved manually using a portable computer, the seals were released, and the packs resumed their transmissions. Given the seals' haulout pattern, approximately 6 weeks were required to transmit and recover the entire data file. This procedure enabled us to compare the data actually collected by the packs with the data received via satellite.

RESULTS

Locations and Movements

Eleven of the 18 location packs (8 on crabeater seals and 3 on Weddell seals) produced usable movements data. No transmissions were received from the other instruments, so it is assumed that they failed very soon after deployment. The duration of successful operations of the packs that did work ranged from 8 to 150 days, with an average of nearly 2 and 3 months for crabeater and Weddell seals, respectively. The length of the location pack transmissions suggests that the attachment method was successful. The total number of locations identified for each seal (including the deployment location) ranged between 3 and 47. Locations were received, on average, about every 5 days for both crabeater and Weddell seals. A summary of these records is given in Table 1.

Given that relatively few transmissions were received via the Argos system compared to the potential number that could have been made by the instrument packs, we assume that most transmissions failed to reach the satellite. When seals were hauled out, transmitters broadcast during the specified period whether or not a satellite was "in view" overhead. Reception by a satellite would also have been hampered by seals' behavior. For example, if a seal was lying on its back, the orientation of its antenna would block any transmission from reaching the satellite. Furthermore, because the PTTs were programmed on a rotating but fixed schedule, if the seal was in the water at the scheduled trans-

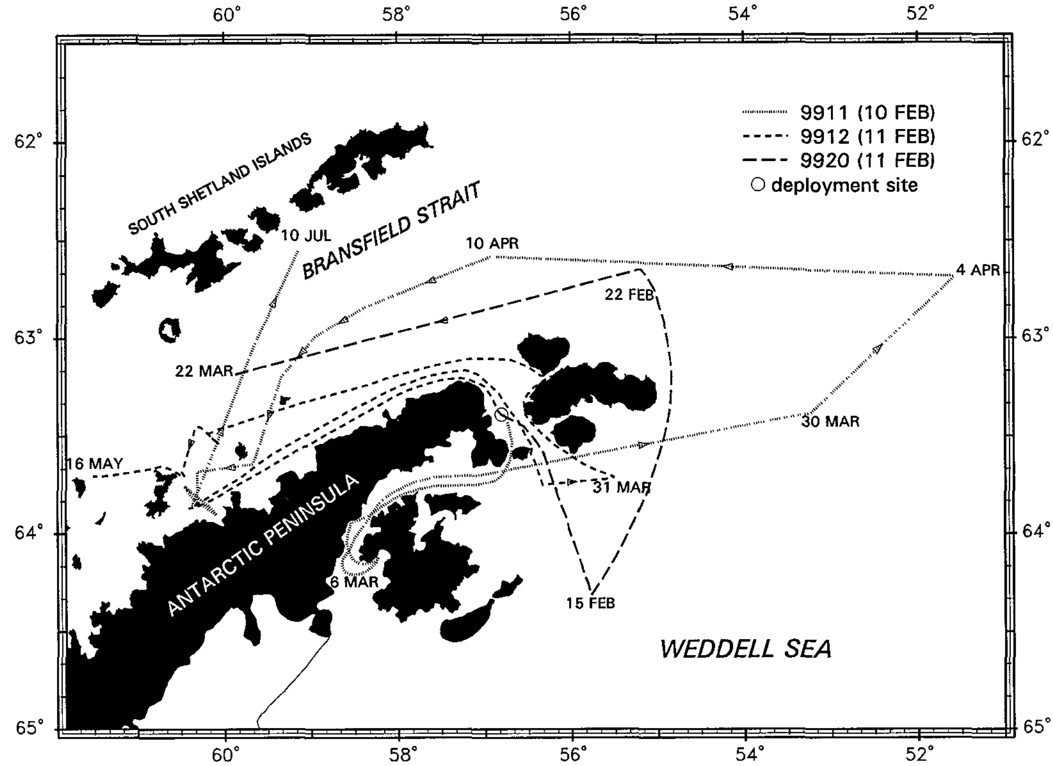

Fig. 1. Seasonal locations movements of individual crabeater seals near the northern tip of the Antarctic Peninsula. The dotted and dashed lines trace the most direct routes between the seals' locations as calculated by the Argos system. All three seals were captured and fitted with satellite-linked transmitters in February, 1986 (the deployment dates are indicated in parentheses after each seals' identification number). The deployment site was in Antarctic Sound, near Hope Bay.

mission time, the transmission would be delayed one day. Crabeater seal haulout data from other studies indicate that individual seals may skip hauling out on as many as 20% of days (Bengtson and Stewart, 1992).

The maximum time period between successive crabeater seal locations was 23 days, and the greatest distance between successive locations was 456 km (over 15 days). Eight of the 11 crabeater seals had records that included multiple locations relayed in a single day. The minimum time between successive estimated locations was 3 min 20 s; this occurred when 2 NOAA satellites passed overhead in rapid succession. The 2 estimated locations were within 1.1 km of each other, confirming good accuracy with the Argos system at these latitudes.

The movement tracks of the 7 crabeater seals whose location packs operated for more than 30 days are shown in Figures 1 and 2. Although some of these records covered several months, the seals tended to stay in the same general region (i.e., usually within a 500 km radius) where they were first encountered. Note also that it was not uncommon for these seals to return to areas occupied in earlier months. The average rate of daily movement is given in Table 1, which must be viewed as minimum distances because no allowance is made for other than straight-line movements. The maximum rates of movement detected were 66 km/day (over a 2-day period) and 12.7 km/h (over a 45-minute period).

Weddell seals ranged much less widely than crabeater seals (Fig. 3). A comparison of the average daily movements between the two species indicates that crabeater seals move significantly greater distances than Weddell seals (18.1 ± 4.5 km/day vs. 3.7 ± 0.9 km/day; $P = 0.01$). During the period for which data are available, the Weddell seals in

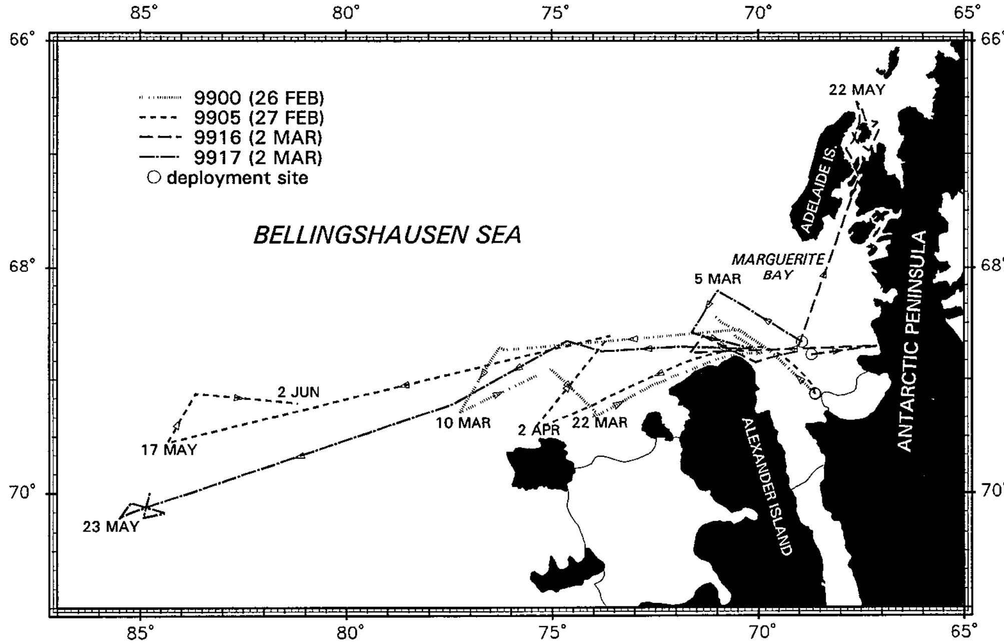

Fig. 2. Seasonal locations and movements of individual crabeater seals near the southwestern portion of the Antarctic Peninsula. The dotted and dashed lines trace the most direct routes between the seals' locations as calculated by the Argos system. All four seals were captured and fitted with satellite-linked transmitters in February and March, 1986 (the deployment dates are indicated in parentheses after each seals' identification number). The deployment sites were in the southern part of Marguerite Bay.

this study remained within about a 150 km radius of the location where they were originally captured.

Reliability of Data Transmissions

A comparison of the 2 data sets (manually retrieved vs. via satellite relay) from the data packs indicated that the accuracy of data relayed via the Argos system is high; however, there are problems with relaying large amounts of sequential data using a transmitter attached to a seal that may not always be in an optimum position for good transmission (i.e., on the ice in clear sight of a satellite). The majority of collected data was transmitted and relayed error-free (Table 2). Lost data tended to be in large blocks rather than scattered throughout the data set.

Figure 4 shows an example comparing manually-retrieved and satellite-relayed data. The upper plot indicates dive records as recovered manually by portable computer; the lower plot illustrates the corresponding data as received through the Argos system, with missing data indicated by gaps in the

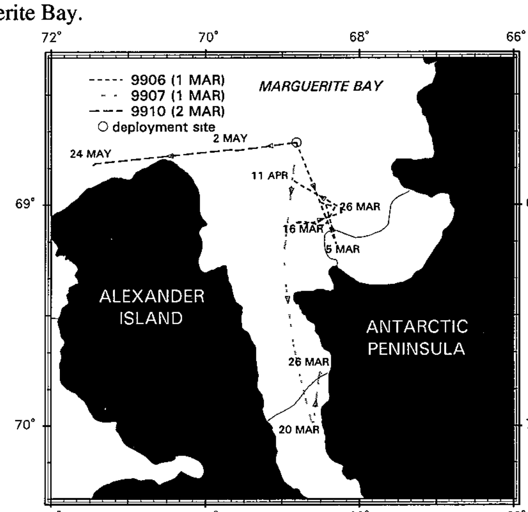

Fig. 3. Weddell seal locations and movements as calculated by the Argos system. The dotted and dashed lines trace the most direct routes between the seals' locations. All three seals were captured and fitted with satellite-linked transmitters in March, 1986 (the deployment dates are indicated in parentheses after each seals' identification number). The deployment sites were in the southern part of Marguerite Bay.

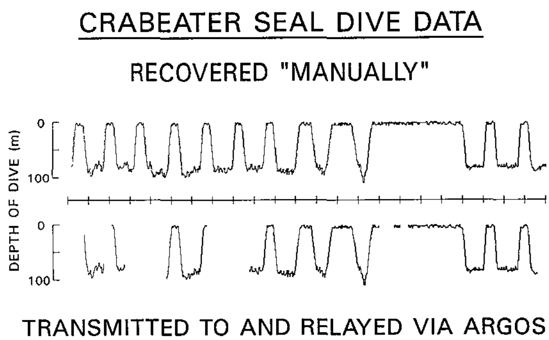

Fig. 4. Comparison of data recovered "manually" and via the Argos system. These plots show crabeater seal dive patterns (the horizontal time ticks indicate 5-minute periods). Gaps in the lower plot (satellite-relayed) resulted from data that were transmitted by the instrument package on the seal but not received and relayed by the Argos system. However, the data that were received by the satellite were transmitted without the introduction of errors.

Table 2. Comparison of data retrieved from instrument packs manually or relayed via the Argos system

Category	Seal No. 1	Seal No. 2
Data transmitted and received correctly	67.50 %	79.40 %
Data transmitted, but not received at all	28.90 %	18.30 %
Data transmitted and received, but corrupted with errors	3.60 %	2.30 %

record. Missing data were almost always absent in relatively large blocks rather than small omissions scattered throughout the data set. These blocks of data probably correspond to transmission attempts while there was no satellite overhead or when the seal was lying on its back, with the radio antenna blocked.

DISCUSSION AND CONCLUSIONS

Of the factors initially identified in this study as critically important for success, the attachment method and potential data corruption did not appear to be major obstacles. The biggest problem in the current study was the high failure rate of these prototype instrument packs. We think that it is likely that leaks in the pressure housings (perhaps exacerbated by corrosion of non-anodized aluminum) or sensor couplings were primarily responsible for these failures. Encasing the electronics in a solid block of epoxy potting instead of a metal pressure housing has given the new generation of instrument packs, which arose from these prototypes and are currently in use, a high level of reliability.

Another improvement in current model of instrument packs for seals is that further advances in microchip miniaturization and power efficiency has allowed reducing the size of the units and extending their battery life considerably. Units are now available that measure 14.5 x 10 x 4 cm, weigh 700 g, and operate for nearly one year. Duty-cycling the data collection and transmission functions of such units can further increase their longevity and efficiency. Of course, the attachment method (epoxied to the pelage) represents a limit on the effective deployment duration of the instruments because they fall off during the seals' annual molt.

Several software techniques can be utilized to increase the efficiency of satellite telemetry for future studies of Antarctic pack ice seals, including onboard processing of data into summaries, use of data compression and codes, and multiple transmissions of messages. Transforming raw data into summaries prior to transmissions can help to overcome the limitation represented by the 32 byte message size allowed by the Argos system. Data summaries will also improve the Argos system's efficiency in receiving transmissions of sequential data. For example, it would require virtually a full 32 byte message to relay the data resulting from a seal's single 5-minute dive if the depth were sampled every 10 s. In contrast, the major features of that same dive could be summarized in about 4 bytes, allowing data on 8 dives to be relayed in one message. Further data compression (e.g., histograms of dive depths or haulout patterns) would reduce the need to transmit dive-by-dive or hourly summaries.

Of the various challenges facing the use of the Argos system for Antarctic seal studies, messages lost because they never reached the satellite remain a significant problem. There seem to be few practical steps that could be taken to avoid missing messages caused by a seal lying in bad positions (e.g., covering the radio antenna with its body), but it should be possible to compensate for messages missed because the satellite was below the horizon during a unit's transmission. Instruments should be programmed to make multiple transmissions of the same message, thereby increasing the probability that the message will be received by the satellite (e.g., once every 10 min during the approximate 110 min period that it takes for a satellite to make one complete orbit around the earth).

Another strategy to optimize message reception would be to program instrument packs to only transmit when satellites are expected to be visible or during periods when the frequency of satellite overflights is at its maximum. However, programming an instrument pack to only transmit during the predicted satellite overflights of a specific geographic location can lead to problems with animals that move long distances. Therefore, it is probably best not to be too restrictive in defining the conditions when units can transmit.

The Argos system promises to be an effective tool for relaying various types of data and for monitoring the location of Antarctic seals. Future studies of the ecology and behavior of Antarctic seals will benefit by making use of this rapidly developing technology.

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