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SHORT NOTE

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Performance of a satellite-linked GPS on Pacific walruses (*Odobenus rosmarus divergens*)

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Abstract We evaluated the utility of a satellite-linked GPS in obtaining location data from Pacific walruses (*Odobenus rosmarus divergens*). A unit was attached to one of the tusks of each of three adult male walruses in Bristol Bay, Alaska. The units were designed to relay GPS positions through the Argos Data Collection and Location System. The GPS was only minimally effective in obtaining location data. An average of only 5% of the attempts yielded a position, and only a small number of these were locations at sea. The paucity of successful attempts was probably due to infrequent and brief surfacings of the GPS, the proximity of cliffs to predominant haul-out sites in the study region, and the packing of animals when they were hauled out in herds. Argos was effective in relaying GPS positions in this study, but as GPS technology advances, and its application to marine mammal studies becomes more prevalent, it seems that the greatest challenge to the study of many species will be in data retrieval.

Introduction

The Argos Data Collection and Location System is the most commonly used satellite system for tracking pinnipeds. Estimated locations vary in their accuracy due to a number of factors, including the behavior of the animal, number of messages received by the satellite, duration of the satellite overpass, distribution of messages received over the course of the overpass, and stability of the transmitter's oscillator (Harris et al. 1990; Keating 1994; Telonics 1996).

Argos locations of most marine mammals are commonly of low estimated accuracy (Born and Knutsen 1992; Goulet et al. 1999), because the animals spend much of their time underwater and few satellite uplinks are acquired. The average error of Argos low class locations (LC ≤ 0) from pinnipeds thus far is generally between 10 and 15 km (Stewart et al. 1989; Born and Knutsen 1992; Burns and Castellini 1998).

In contrast to the Argos location system, the Global Positioning System (GPS) consistently produces accurate estimates. GPS horizontal estimates are expected to fall within 100 m (Selective Availability activated; this study) or 5 m (Selective Availability deactivated) of their true location 95% of the time (Rodgers et al. 1996; Dussault et al. 2001). In addition, GPS animal tracking allows greater temporal coverage than Argos, and does not require screening of raw data by the researcher (Rodgers et al. 1996; Telonics 1996). The fine spatial and temporal resolution of GPS positions can support detailed habitat and resource utilization studies.

Although GPS tracking is proving useful in terrestrial applications, we are aware of only two studies that have deployed a GPS on marine mammals, and both used data-logging systems that required recovery to download the positions. In a study of the Hawaiian monk seal (*Monachus schauinslandi*), three GPS data-logging units were attached to the back of the study animals, but the deployments experienced only limited success (only eight positions during a 3-day period, Sisak 1998). A tethered floating tag was successfully used on the West Indian manatee (*Trichechus manatus*) (Deutsch et al. 1998), which in later models incorporated a GPS data-logging system (Reid et al. 1999). Much of its success was due to the manatee's herbivorous diet, resulting in restriction of the animal's distribution to shallow coastal waters, the animal's typically sedentary behavior, and the ability of researchers to attach tags without animal capture or restraint (Deutsch et al. 1998).

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We describe the performance of a satellite-linked GPS on the Pacific walrus (*Odobenus rosmarus divergens*). This is the first report of a satellite-linked GPS deployed on a marine mammal. We recognize that aspects of the performance of this system were partly dependent on walrus behavior and user-specified options such as the duty cycling of acquisition attempts. Nevertheless, this information demonstrates the use of this system on a pinniped and highlights factors that should be considered in using a GPS system for tracking marine mammals.

Materials and methods

In August 1996, a satellite-linked GPS (Telonics, Mesa, Ariz.) was attached to one of the tusks of each of three adult male Pacific walruses in Bristol Bay, Alaska. The units acquired GPS positions and relayed the positions through the Argos Data Collection and Location System.

GPS positions were calculated onboard the unit after receiving data from high-orbiting GPS satellites. A GPS fix was attempted for three continuous minutes at the first instance that the conductivity sensor detected a dry condition during a 1-h on-period of a duty cycle of 1 h-on/7 h-off beginning at 0300 hours GMT (i.e., all on-periods started at either 0300, 1100, or 1900 hours GMT). If a fix was not obtained within the 3-min period, no further attempts were made until the next scheduled on-period. A non-volatile memory buffer in the unit stored up to seven GPS positions and their corresponding date and time of collection (seconds truncated).

In addition to relaying GPS position data, the Argos system generated conventional Argos location estimates. Transmissions from the unit were received by overpassing NOAA satellites and the transmitter's location was estimated using detected Doppler shifts (Harris et al. 1990). At least two transmissions during a satellite overpass were required to obtain an Argos location estimate. Each unit transmitted a 1-W signal once every 90 s during a 4-h on-period of a duty cycle of 4 h-on/25 h-off/4 h-on/15 h-off beginning at 1700 hours GMT (i.e., all on-periods started at either 1700 or 2200 hours GMT).

We used an Argos duty cycle that optimized the time a satellite was in view (Telonics 1995). Two satellites were in service (multiple satellite service) during the study period (2 August to 26 October). During each Argos on-period, 3–6 satellite overpasses were predicted to have occurred ($\bar{x} = 4.8$, SD = 0.7, $n = 173$), each lasting 8–16 min ($\bar{x} = 12.2$, SD = 2.7, $n = 836$)with a maximum elevation of 3–89° ($\bar{x} = 25.2$, SD = 23.6, $n = 836$). Argos processing included auxiliary location processing (i.e., location classes A and B provided).

At the time of an Argos transmission, all GPS positions contained in the buffer were encoded and transmitted in the sensor data of the transmission. Hence, each Argos transmission received by the satellite (uplinked) included transmitter information as well as sensor data, which contained up to seven encoded GPS positions. More than one Argos uplink was required to obtain an Argos location estimate from the satellite overpass, but each uplink always included sensor data.

Argos transmissions were deferred during those GPS activation periods (≤3 min) that coincided with an Argos attempt period (once every 48 h when the GPS 1900 hours 1-h on-period coincided with the Argos 1700 hours 4-h on-period). In addition, each unit possessed an external conductivity sensor and, to conserve battery life, GPS fixes and Argos transmissions were not attempted when the conductivity sensor detected that the unit was submerged.

The outcome of each attempt to fix a position by the GPS during its on-period was classified as a success or failure. Intervals between Argos uplinks were examined to identify potential GPS attempts that could not be classified because of information being overwritten in the GPS memory buffer during a prolonged period of unsuccessful Argos uplinks. Only one such GPS attempt occurred and was omitted from analysis. Successful GPS attempts were classified by habitat (land or water) using GIS.

Although the units were functional for up to 6.5 months after deployment, we restricted our analysis to data collected before 27 October, when the area inhabited by the animals was free of sea ice. This was to ensure that we could classify GPS positions by habitat, because walruses commonly haul out onto ice when it is available. The period of ice-free conditions was determined from inspection of NOAA National Ice Center sea-ice charts of the eastern Bering Sea (http://www.natice.noaa.gov/).

Results and discussion

The frequency of successful attempts by the GPS to fix a position indicates that the units were only minimally effective in obtaining location data (Table 1). An average of only 5% of the attempts yielded a position, and only a small number of these were locations at sea. The proportion of successful attempts did not vary significantly among animals ($\chi^2 = 1.99$, $df = 2$, $P = 0.37$).

The percentage of Argos on-periods that yielded an uplink varied considerably among the 3 animals (23–84%, Table 1). Some variation was probably due to differences in the amount of time that was allocated to foraging and hauling out by each animal; however, the number of uplinks from animal no. 2 was unusually low.

On average, the GPS acquired about 4 times more land positions than at-sea positions, but fixes were infrequent in both habitats. A separate study using time-depth recorders demonstrated that adult male walruses, in the same region and season as the present study, spent about 23% of their time on land and 30% of their time at the water's surface (Jay et al. 2001).

The paucity of fixes at sea was probably due to infrequent and brief surfacings of the GPS. The GPS required about 40 continuous seconds at the surface to obtain a fix (Rodgers et al. 1996; Telonics 1996). The animals in this study probably spent only 1–2 min at the

Table 1 Frequency of GPS on-periods (during which a position fix was attempted) of a 1 h-on/7 h-off duty cycle, and of Argos on-periods (during which uplinks were attempted) of a 4 h-on/25 h-off/4 h-on/15 h-off duty cycle

	Habitat	Animal [observation period]			
		1 [85 days]	2 [65 days]	3 [65 days]	$\bar{x}$
GPS on-periods		258	194	195	
Periods yielding a position (%)	Water	3 (1.2)	3 (1.5)	0 (0.0)	(0.9)
	Land	14 (5.4)	4 (2.1)	10 (5.1)	(4.2)
	Total	17 (6.6)	7 (3.6)	10 (5.1)	(5.1)
Argos on-periods (% yielding an uplink)		86 (83.7)	66 (28.8)	66 (68.2)	(60.2)

surface between dives during bouts of diving (Jay et al. 2001), and it is likely that the GPS was often only briefly visible at these times. However, walruses occasionally rest at the surface in a vertical position with their tusks held above the water for prolonged periods with the aid of pharyngeal pouches, which the animal inflates with air (Fay 1960). Tusk-mounted tracking devices, such as the units in this study, would probably acquire most of their at-sea location estimates during these extended rest periods.

Although the GPS acquired more positions from land than water, only 4% of all fix attempts yielded a position from land, which is lower than might be expected from the probable amount of time the animals were hauled out (~25%, Jay et al. 2001). One reason for acquiring a small number of land positions may be the close proximity of cliffs to the predominant haul-out sites in the study region, which would hinder the GPS in receiving signals from satellites overhead. Furthermore, walruses typically haul out in dense aggregations and in close contact with one another. It is probable that when a tagged animal hauled out, the GPS was frequently in an oblique position, or was obstructed by the tagged animal or its neighbor.

In this study, we used a satellite-linked system to recover GPS positions because walruses are generally difficult to recapture. Although few GPS positions were acquired, the Argos system was an effective link in relaying the GPS data. An added advantage of using the Argos system for data retrieval was that the system was capable of producing location estimates of its own, albeit usually much less accurate than those from GPS. The configuration of the Argos location system in this study resulted in roughly 1–2 Argos on-periods with at least one location estimate for every position that was fixed by the GPS. The GPS that was used in this study might be improved by extending the single 3-min activation period to several activation periods during the 1-h on-period, and by shorter GPS fix times from future technological advances.

Although future studies may be able eventually to achieve reasonable success in acquiring GPS positions of marine mammals, retrieval of the data may still be problematic in many situations. A disadvantage to the Argos satellite-linked retrieval system is that the quantity of GPS positions that can be downloaded is limited by the 256-bit maximum capacity of sensor data in an Argos transmission, and potentially by the rate of successful Argos uplinks that can be achieved. If a satellite-linked GPS were configured to acquire GPS positions at a rate that exceeded the rate that data could be transferred through the Argos uplinks, then some GPS data would be lost.

In cases where the study animal can be recaptured, large amounts of GPS data could be logged in non-volatile memory and downloaded after the device was recovered (Telonics 1996; Sisak 1998; Reid et al. 1999). Alternatively, if the animal can be approached closely, the data could be recovered across a direct radio link (Telonics 1996). In an example of this type of GPS data retrieval from moose (*Alces alces*), a radio link had a line-of-sight operating range of >15 km from an aircraft and the system downloaded 200 positions in about 2.5 min (Rodgers et al. 1996). As GPS technology improves, it seems that the development of methods for data retrieval from GPS data-logging systems will be our greatest challenge in applying GPS tracking to a broad range of marine mammals.

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