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SHORT COMMUNICATION

Performance and accuracy of Argos transmitters for wildlife monitoring in Southern Russia

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Abstract Satellite telemetry is a powerful tool for monitoring animal movements, and Argos transmitters have been widely used. Unfortunately, only few studies have systematically evaluated the performance of Argos satellite collars for wildlife monitoring. We tested Argos satellite telemetry transmitters at two power levels in Southern Russia (five transmitters at 0.5 W and three at 1 W). Performance metrics were derived from the number and accuracy of location estimates and the number of days on which collars transmitted or failed to transmit data. Our results suggest that the performance of Argos collars in our study region was poor. At the power level of 0.5 W, 55% of the sessions resulted in at least one transmission, but only 21% provided a location estimate. The percentage of successful sessions did not increase much after setting the power level to 1.0 W (63%), but the increase in the number of location estimates was considerable (54%). At either power level, the majority of the location estimates were in the low quality classes though (80% nonstandard locations with 0.5 W and 45% with 1 W). Positional accuracies were 0.5, 0.7, 1.5, and 4.6 km for location classes 3, 2, 1, and 0, respectively. For nonstandard location classes A and B, positional accuracies were 2.1 and 18.3 km. Careful testing of transmitters is recommended before deployment, as the location of the study area can seriously affect performance.

Keywords Argos · Satellite telemetry · Accuracy · Performance

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Introduction

Satellite telemetry is a powerful tool to monitor the movement of wild animals (Fancy et al. 1988). Argos satellite transmitters in particular have been used in many ungulate studies since the 1980s, for example, for caribou (*Rangifer tarandus*; Tamstorf et al. 2005) and camelids (*Camelus dromedarius*; Grigg et al. 1995). The advent of Global Positioning System (GPS) receivers has limited the use of Argos platforms somewhat, but Argos collars continue to be used, for example, for Mongolian gazelles (*Procapra gutturosa*; Ito et al. 2006) and desert bighorn sheep (*Ovis canadensis*; Boyce and Weisenberger 2005) because Argos transmitters are cheaper and weigh less. The positional accuracy of Argos collars is poorer than that of GPS collars, but this may not matter for some applications, and the advantage of Argos is the ability to transmit data back to the satellite and from there to the end-user, which eases the recovery of the collected data. Alternative approaches to recover data are often not an option for animal species that migrate large distances because they are either logistically infeasible (i.e., drop-off mechanisms and transmission via ultra high frequency), limited by lacking infrastructure (i.e., cellular phone network), or prohibitively expensive (i.e., satellite phone transmitters). Combined GPS/Argos systems are a big step forward in terms of positional accuracy, but might still suffer from performance issues related to the transmission of the data to the satellites.

To date, only few studies have quantified the performance and positional accuracy estimated with Argos transmitters (Keating et al. 1991; Vincent et al. 2002; White and Sjoberg 2002). Unfortunately, differences in experimental design and equipment (region, species, transmitter models, power level, terrain) preclude generalizing those estimates. And the performance of the transmitters, i.e., the number of successful transmissions relative to the number of satellite overpasses, has rarely been reported.

Another knowledge gap is how power levels of the transmitters affect collar performance. The assumption is that for large vertebrates (>10 kg), the issues of performance and accuracy are less critical because higher power levels (≥0.5 W) can be used (Britten et al. 1999; Soutullo et al. 2007). However, some studies suggest that transmitter performance can already be severely limited even at a power level of 0.5 W (Kaczensky and Walzer 2006), which is typical for mesopredators and small ungulates. And higher power levels reduce battery life considerably, making information about the minimum power level important for planning.

Finally, most telemetry accuracy studies have been conducted in North America. This constitutes an important limitation for the estimation of the overall accuracy of Argos telemetry because there is some evidence of reduced satellite performance especially in Southern Europe and Central Asia highlighting that Argos performance evaluations are somewhat site specific (Gros et al. 2006).

Our overarching objective here was to quantify the performance of Argos satellite transmitters for ungulate telemetry in southern Russia (Republic of Kalmykia), and we were particularly interested in the effect of power levels on transmitter performance.

Methods

Satellite transmitters and transmitter testing We tested five 550 g satellite radio-collars (Telonics Inc., ST-20 PPT, transmitter model 3210). Locations were estimated and obtained from the Argos system for all location quality classes (Location Service Plus). The Argos system uses transmitters that periodically send a short radio signal to one of several polar-orbiting NOAA satellites. This data is retransmitted to a data processing facility where the location of the transmitter is calculated based on the Doppler shift in the frequency of messages received by a satellite as it approaches and then moves away from the transmitter during a single overpass. The accuracy of the location estimates depends on the number of messages received during the overpass. Based on the number of messages, each location is assigned a level of accuracy, a so-called location class (Fancy et al. 1988; CLS 2007).

Our transmitters were set to transmit between 08:00 and 12:00 Coordinated Universal Time to coincide with the highest number of NOAA satellite overpasses in our study area. At least three of the six NOAA satellites that can receive Argos signals were present over the study area during each duty cycle. Multisatellite processing was turned on to receive location estimates from multiple satellite overpasses. Data presented here were collected either when collars were stationary (on a rooftop) or when collars were mounted on saiga antelopes (*Saiga tatarica*) held in a small enclosure (27 ha). All work with the saiga antelopes was conducted under Animal Use Protocol A01131-0-08-06 approved by the Animal Care and Animal Use Committee of the University of Wisconsin-Madison, which is registered with the U.S. Department of Agriculture.

The testing of the collars occurred during two main periods. During period 1 (March–December 2004), all five collars were set to transmit every 3 days, and the power level was set to 0.5 W. During this first period, the transmitters were mounted on saigas freely moving in the enclosure. Due to limited performance during period 1, all five collars were reprogrammed in December of 2004, which constituted the beginning of period 2. Two transmitters stopped functioning after reprogramming. For the remaining three collars, the power level was increased from 0.5 to 1 W. For two collars, the duty cycles were set to 1 day and power level increased to 1 W and they transmitted from December 2004 to April 2005. For the remaining transmitter, the duty cycle was set to a 7-day interval and this transmitter operated from April to September of 2005. During the second period with the higher power levels, all transmitters were held stationary (on a rooftop, 2 m high).

Data analysis Data were processed using Argos-tools extension for Arcview GIS 3.x (Potapov and Dubinin 2005), and we calculated three performance statistics for the two periods.

Successful sessions and transmissions Defined as the percentage of sessions that resulted in at least one transmission and the percentage of sessions with enough data to provide a location estimate. The potential number of sessions according to duty cycle was calculated separately for each transmitter; the end of transmitter lifetime was determined by the last successful session. As there might be more than one transmission during a session, the total number of transmissions was also calculated.

Location classes (LC) Defined as the percentage of both standard quality classes 3, 2, 1, or 0 (LC 3, LC 2, LC 1, LC 0) and nonstandard locations quality classes A or B (LC A, LC B).

Positional accuracy Defined as the Euclidean distance between the Argos location estimate and the known location of the collar. Additionally, we calculated both latitude and longitude distance errors (calculations made in Universal Transverse Mercator projection, zone 8). We used 68th percentiles to define accuracy of locations. The 68th percentile estimates allowed for straightforward comparisons with other studies and official Argos estimates (CLS 2007).

Possible effect of climate on transmitter performance was assessed using logistic regression. Differences among the proportions of successful transmissions in each quality class before and after power change were estimated using Fisher's exact test, and the p value was estimated using a Monte-Carlo simulation with 10,000 replicates. We used the success measure (0—no message, 1—one or more messages) for the three transmitters that did not fail as the response variable, average temperature on the day of transmission or daily temperature amplitude ($T_{max}-T_{min}$), and collar as the predictor variables. Temperature data were obtained from a nearby weather station located in Elista.

Results

The majority of the sessions were provided by three of our five collars (Table 1). Only 58% of the sessions were successful and 33% of the sessions provided enough data to estimate locations. Of 545 collected transmissions in total, 55% contained locations, out of which 39% were standard locations.

The absolute number of the locations for LC 3–LC 1 for power level 1 W was 7.5 times larger than for power level 0.5 W (114 versus 14 locations). Increasing the power level also significantly increased the number of successful sessions and the accuracy of the location estimates. Only 20% of the locations were of high quality LCs (LC 3–LC 1) before the power level increase in period 2, but more than 50% after. However, the increase in total numbers of nonstandard quality locations was not as substantial (62% for LC A and 54% for LC B locations). The share of nonstandard quality locations decreased from 39% and 41% to 21% and 27% for LC A and LC B, respectively.

Period 1. During period 1, transmitters operated for a total of 301 sessions. On average, for five collars, 55% of the sessions resulted in a transmission, but only 21% of sessions resulted in a location estimate of any class. Of the 235 received transmissions, only 32% contained coordinates, and of those, only 19% were standard locations with a location error estimates. In other words, transmitters provided 0.1 to 0.3 locations per session. All five collars exhibited similar performance during period 1 (Table 1). The proportion of transmissions with location estimates in each LC and performance did not differ significantly among PTTs (p=0.23 and p=0.862).

Period 2. During period 2, transmitters operated for a total of 184 sessions. On average, for the three collars that remained, 63% of sessions resulted in a transmission and 54% of the sessions resulted in a location estimate of any class. Of a total of all

Table 1 Summary performance measures for periods before and after power increase

Location class								Performance measures					
Power level (W)	Collar ID	3	2	1	0	A	B	Number of locations	Time period	Number of sessions	Number of successful sessions	Number of sessions with location	Number of transmissions
0.5	44649	2	2	1	0	5	15	25	04.2004–12.2004	86	51	18	85
0.5	44650	0	2	0	0	5	3	10	07.2004–12.2004	54	30	10	35
0.5	44651	1	1	1	1	9	5	18	07.2004–12.2004	53	31	13	46
0.5	44652	1	1	1	0	3	6	12	07.2004–12.2004	54	31	12	40
0.5	44653	0	1	0	0	7	1	9	07.2004–12.2004	54	23	9	29
Subtotal		4	7	3	1	29	30	74		301	166	62	235
1.0	44649	11	18	13	4	9	11	66	12.2004–04.2005	75	42	36	93
1.0	44651	3	3	2	3	8	9	28	04.2005–09.2005	23	19	16	41
1.0	44653	12	24	18	13	30	36	133	12.2004–04.2005	86	55	48	176
Subtotal		26	45	33	20	47	56	227		184	116	100	310
Total		30	52	36	21	76	86	301		485	282	162	545

310 transmissions obtained during this period, 73% provided position estimates, of which 46% were standard locations that included location error estimates, and 54% were nonstandard locations. The proportion of locations in each LC and performance did not differ significantly among PTTs (p=0.16 and p=0.20).

When collars were held constant, the 68% percentile for positional accuracy of LC 3, 2, 1, and 0 was 458, 666, 1,456, and 4,633 m, respectively, and for LC A and LC B error was 2,126 and 18,399 m. Accuracy of LC A locations was comparable with LC 1 and outperformed LC 0. The major error source for all LC was longitudinal error, which was two to three times greater than the latitudinal error.

Neither average daily temperature nor amplitude was significantly related with the success of transmission at 0.05 level for either entire period of the study or for periods 1 and 2, individually.

Discussion

The performance of the Argos transmitters, especially in the first period was considerably lower than we had expected based on other studies (Keating et al. 1991; Vincent et al. 2002; White and Sjoberg 2002). Only 55% of all sessions resulted in a message, only 21% of the sessions resulted in a successful location estimate, and only 19% of the obtained locations were in the high quality location classes. In comparison, Keating et al. (1991) report ≥1 sensor message for up to 64% of satellite passes and a location estimate for 63% of such passes.

Besides simple transmitters malfunctioning, there are several potential explanations for the low performance that we observed. Though we could not account for all possible sources of error in this study, we suggest that other error sources were likely minor. Other possible sources of error include: (a) distance to the ground, (b) temperature, and (c) change in duty cycle. Elevation change can affect avian species or animals moving seasonally between different altitudes (i.e., hundreds of meters difference; Keating et al. 1991). However, the difference in elevation between the time when collars were mounted on the saiga and when they were on the rooftop was only 2 m, and we suggest that this would have been of negligible importance. Temperature is an important factor determining stability of the frequency of transmitter and potentially affecting their performance, and our transmitters indeed were operating under different seasonal temperatures. However, we did not observe any systematic changes in the performance related to temperatures and observed sudden drops in performance did not coincide with temperature changes. Finally, we suggest that the changes in the duty cycle did not have a major effect on our performance estimates because we ensured that each duty cycle included the time of the day when the highest number of satellites was present.

Based on our results, we conclude that the low performance is most likely due to elevated background noise levels in the region. Argos instruments are receiving broadband noise in Southern Europe that makes it difficult to demodulate messages that are reaching satellite with a power level of −130 dBm or less (Gros et al. 2006). The improvement in numbers of high quality locations after our power level increase in period 2 suggests that even in the open environment of the Western Caspian plains, power level of the transmitters has to be fairly high to overcome noise, which is a recognized problem for low-power transmitters (<0.5 W) used for small animals (Soutullo et al. 2007). We also note that the location of the study site is still about 300 km outside the −130 dBm isoline identified by CLS as the main area of concern (Gros et al. 2006). Our results thus suggest that noise problems are more widespread than previously reported, confirming other studies and observations (Kaczensky and Walzer 2006; Microwave Telemetry 2007).

Though considerably more locations of better quality were received after the increase in power level, still about 46% were nonstandard. The positional accuracies remained on the order of several hundreds of meters to thousands of kilometers (depending on LC), comparable to other studies (Table 2). This is particularly worrisome because accuracy estimates obtained from a stationary collar are positively biased compared with collars mounted on animals that are moving (White and Sjoberg 2002). Our location accuracy values thus represent a best-case scenario.

The assignment of a given transmission into a location class is based on plausibility tests and assignments provide

Table 2 Positional accuracy estimates (m) reported by the Argos service provider, and in other studies (68th percentile)

ID	LC 3	LC 2	LC 1	LC 0	LC A	LC B
This study	458	666	1,456	4,633	2,126	18,399
CLS, 2007	150	350	1,000	>1,000	N/A	N/A
Keating et al., 1991	361	903	1,188	1,290	N/A	N/A
Vincent et al., 2002	226	372	757	2,789	1,384	5,905
Soutullo et al., 2007	N/A	N/A	4,000	15,300	20,000	59,100

LC 3 and LC 2 estimates in Soutullo et al. (2007) are 300 and 1,300 m, respectively (n=1) a good relative ranking, but the assigned location classes are not always a reliable proxy for location quality. As previously shown (White and Sjoberg 2002; Soutullo et al. 2007), positional accuracy of lower quality locations can be similar to higher quality location, and in our case, LC A was comparable with standard LC 1 locations for the 68% percentile. This suggests that these lower quality locations can provide valuable information and should not be discarded. However, if a high precision of the location estimates is crucial for a given study, then location estimates should be filtered based on their location class or other plausibility tests to include only the most reliable estimates (Britten et al. 1999; Hays et al. 2001; Potapov and Dubinin 2005).

In summary, Argos satellite telemetry is a useful tool to gather information on animal locations especially where no other means of retrieving data is possible. However, some issues of concern about Argos technology, like elevated noise levels in some areas have only been highlighted recently (Gros et al. 2006). Anecdotal reports about malperforming collars far surpass the number of published studies that quantify the performance of current tracking technology and discuss limitations. We suggest that overcoming current technological limitations will require stronger commitment by the scientific community to conduct rigorous tests of available equipment and to publish these results. Our results highlight that Argos collars require extensive testing and likely reprogramming before they can provide useful data consistently and that some regions of the world may simply not be suitable for Argos-based wildlife monitoring.

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