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Some Practical Guidelines for Users of the ARGOS Satellite-Telemetry System

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Abstract

The Argos location and data collection system has been used widely in wildlife research though many workers have identified problems with it, particularly its lack of precision. The Indochina Elephant Programme (Fauna & Flora International) and the Cambodian Forestry Administration undertook a satellite telemetry project in Cambodia, which ended prematurely due to an apparent failure in the system. The transmitter was recovered and several methods used to determine when the system failed as well as to calculate error estimates for the PTT-derived data. It was discovered that the collar had become static only five months into the study and that LC 3 provided the most reliable locations, followed by LCs A & 2. Users of the Argos system are strongly advised to make their own error estimates and although these tests use ad hoc data, modification to suit pre-deployment tests would be straight-forward.

Introduction

The study of animal movements through satellite telemetry has played an increasingly important role in conservation biology over the past couple of decades. One of the most widely used, the Argos location and data collection system, is operated and managed by Collecte, Localisation, Satellites (CLS). This system utilizes dedicated receivers placed on-board several polar-orbiting satellites, which collect and analyse signals (up-links) from Platform Terminal Transmitters (PTTs). This data is then relayed to processing centers, in France and America, where the PTT's location during the initial up-link, is calculated. This final calculation is based on the change in frequency of the original signal as the satellite passed overhead; the Doppler shift effect. The result is sent to the system user in the form of a lat/long location in decimal degrees. Each location is classified into one of seven Location Classes (LC) four of which (LCs 0-3) give an estimation of the locations accuracy (Table 1).

Table 1. CLS error estimates.

Location Class	Accuracy
3	< 150m
2	150 m accuracy < 350 m
1	350 m accuracy < 1000 m
0	> 1000m
A	No estimate of accuracy
B	No estimate of accuracy
Z	Invalid location

The performance of the system depends on several factors that affect both the transmitter (e.g. altitude, latitude, topography and oscill-ator stability) and the on-board receiver (e.g. geometrics, number of messages and their dis-tribution in time). Any combination of these factors acting upon the system means that its overall performance can vary both within and between studies (Keating *et al.* 1991).

Operational since the 1970's the system has been used widely in wildlife research and has been increasingly applied to the study of both African (Lindeque & Lindeque 1991; Tchamba *et al.* 1995; Verlinden & Gavor 1998; DeBoer *et al.* 2000) and Asian elephants (Stuwe *et al.* 1998; Goldthorpe & Heffernan in press). Although the use of the system has resulted in a plethora of information, many workers have identified problems with it including locational inaccuracy (Hillman-

Smith *et al.* 1995; Stuwe *et al*. 1998; Verlinden & Gavor 1998; Hays *et al.* 2001; Minton *et al.* 2003), sporadic signal reception (Stuwe *et al.* 1998), failing batteries (Tchamba *et al.* 1995; Dietz *et al.* 2003) and unexplained PTT failure (Stuwe *et al.* 1998; Verlinden & Gavor 1998). Despite this the system continues to be used and improve-ments made (Gillespie 2001; Mech & Barber 2002).

The issue of locational accuracy has provided perhaps the most attention from workers possibly because it is not caused by a function in the equipment but is rather a conglomerate of several technical and environmental considerations that cannot, themselves, be corrected. As a result, users are advised to calculate their own error estimates (Hays *et al*. 2001) several examples of which exist in the literature (Fancy *et al*. 1989; Keating *et al.* 1991; Keating 1994; Minton *et al*. 2003).

Fauna & Flora International (FFI), in collaboration with the Cambodian Forestry Administration, undertook a satellite telemetry project in the Cambodian province of Mondulkiri to map the home range and habitat features of resident Asian elephants. A male adult elephant was successfully collared and tracked for 113 days using a KiwiSat 101 PTT programmed with a 3/9 hour Duty Cycle (Goldthorpe & Heffernan in prep.). Around seven months into the study it became apparent that the transmitter was static, and the study was ended prematurely. As the PTT was still transmitting it was recovered and attempts made to determine, as closely as possible, the point of failure so that a usable data-set could be extracted for analysis. The opportunity to calculate independent accuracy, or error, estimates from the data received was also taken.

During the study period it was also discovered that the calculations made by CLS result in a location that is rounded to the nearest three decimal points (Fabienne Vigier pers. com.). When viewed in the ArcView Geographic Information System (GIS) this coarse resolution results in the ordering of points into a grid which can severely bias calculations made in some of the GIS home range analysis functions (Phillip Hooge pers. com.). Despite this, the problem of rounding has not, to the author's knowledge, been dealt with in the literature elsewhere; an oversight made even more mystifying when considering the ease with which it can be accounted for.

This paper details methods, used to overcome these problems so that future users of the PTT system can easily identify and deal with them as they occur.

Methods

Identifying time of collar failure

The time at which the transmitter became detached from the elephant was not immediately apparent. Unlike radio-telemetry, where a static transmitter is relatively easily identified by a series of near-identical signals (Kenward 2001) satellite-derived locations can still appear spread over a relatively large area due to their inherent inaccuracy (Dan Kelly, pers. comm. & personal observation). To increase the likelihood of identifying the correct time of detachment, several methods were applied with a focus on high-quality locations. All analysis was carried out on LC data-sets separately.

Method 1: Calculating distances between the point of recovery and each received location

With the position of the static transmitter known, it was possible to calculate the distance between each PTT-derived location and the point of transmitter recovery in excel using the formula:

$$\sqrt{\left((X_{Known} - X_{\mathrm{Re}ceived})^2\right) + \left((Y_{Known} - Y_{\mathrm{Re}ceived})^2\right)}$$

Average distances for each calendar month were then calculated and a visual comparison made by way of a standard bar chart. It was assumed that the time of detachment would be shown as a clear and consistent reduction in the distances between the point of recovery and the PTT-derived locations.

Method 2: Calculating distances between cumulative locations

Distances between successive PTT-derived locations were calculated, using the ArcView extension “Path, with Distances and Bearings” (Jenness 2003) and averaged for each month. Again, results were displayed in the form of a standard bar chart for visual inspection and the point of detachment associated with a clear and consistent reduction in successive distances.

Method 3: Overlaying ArcView accuracy buffers

Each LC data-set was further categorized by month and plotted in ArcView along with the known location. Around the latter, buffers based on the error estimates given by CLS (Table 1) were created using the “Create Buffers” function. Through the systematic removal of each month’s data it was possible to see at what point the majority of remaining locations occurred within the relevant buffers. This would represent the point at which the transmitter became static.

Calculating error estimates

All data collected from the active PTT between the time identified as the point of detachment and the day the PTT was recovered was considered as originating from the same geographical point. This point had been recorded on a hand-held Garmin GPS unit giving a reliable (± 10 m) UTM (WGS 84) for the PTTs’ true location.

These data were transferred into an excel workbook and grouped according to their LC. The distance (meters) between each received location and the transmitters true location was then calculated using the formula:

$$\sqrt{\left((X_{PTT} - X_{GPS})^2\right) + \left((Y_{PTT} - Y_{GPS})^2\right)}$$

Standard deviation (n-1) and 95% Confidence Intervals were also calculated to provide a statistical measure of reliability (Dytham 1999). The presence of large intervals in some of the data-sets indicated the presence of outliers and box-plots were constructed, using the SPSS “Explorative Statistics” function, to identify these values. The PTT-receiver tele-metry system is affected by external factors such as the relative movements of the satellite and the PTT or even the level of cloud or canopy cover between the two. These, in turn, can influence the data-processing carried out by the on-board receiver which itself relies on the quality of up-links. Transmissions calculated on the boundary of the systems acceptance parameters can, then, result in erroneous locations (Keating 1994) the presence of which will skew results when averages are involved (Dytham 1999).

Rounding of decimal degree locations

Finally, in order to overcome problems that can be experienced by some ArcView functions through overlapping points (Philip Hooge pers. com.) the ArcView extension “Random Point Generator” (Jenness 2004) was used. This extension enables the user to generate a set of random points by moving an original point in a random direction for a random distance within a user-defined para-meter. In this case, movement distances were set according to the error estimates calculated for each LC as detailed above.

Results

Identifying time of collar failure

The results gained from each method applied to the data-set showed a severe reduction in the spread of locations occurring sometime in early August (Figs. 1-4). It was decided therefore, that all pre-August data represented actual elephant movements and could be used in subsequent home range analysis whilst that collected in and after August would be re-jected (Goldthorpe & Heffernan in prep.).

Calculating error estimates

A summary of the post-detachment data is given in Table 2. There are notable variations in the number of locations received within each LC with the total number received for LCs 0 & 1 being extremely low (these were excluded from subsequent analysis). To ensure that accuracy estimates were not affected by sample size all data-sets were equalized (Kevin Lay pers. com.). The range shown by some of the data sets provides an initial indication of the precision of each. Even with outliers removed, the range displayed by LC B data is huge (99 – 9567 m) whilst that of LC 3 is far smaller (17 – 228 m). The range displayed by LC A is also interesting in that it was dramatically reduced, with a difference of 2400m between the two upper ranges, prior and subsequent to outlier removal. This indicates that, although LC A locations tend to be accurate they must be treated with caution due to an increased likelihood of erroneous locations when compared with both LCs 3 & 2.

The average (mean) distance between each LC's calculated location and the true location of the PTT were deemed to be the true measure of location accuracy and are given as the radius of a circle (Table 3). When imported into ArcView it is possible to translate these error estimates into buffer-zones around the known location of the PTT (Fig. 4). These were used to calculate, for each LC data-set, the percentage of points that occur within their associated zone of error by clipping each LC point theme with the relevant buffer polygon. The attribute table that ArcView produces contains only those points within the buffer and can be compared with the original table to provide a percentage of the total (Table 3) and

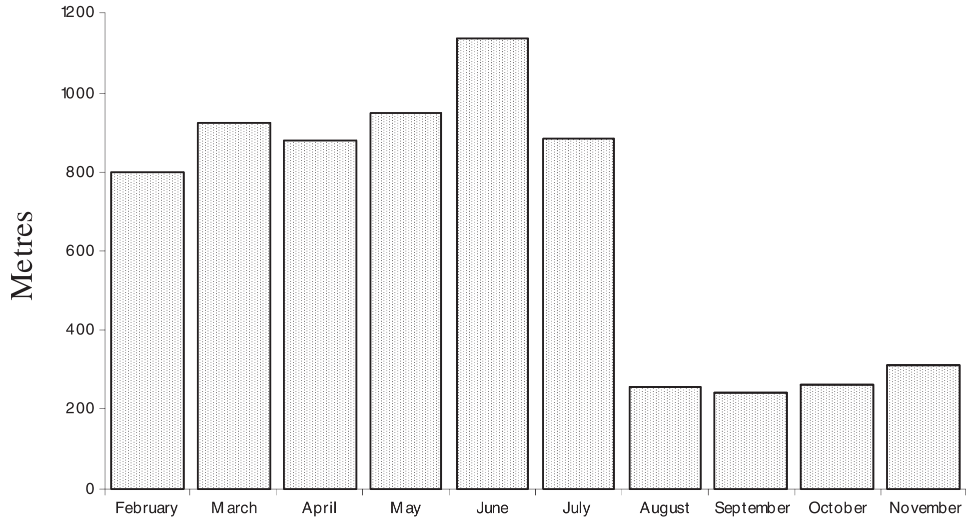

Figure 1: Average monthly distances between PTT-derived locations and recovery point

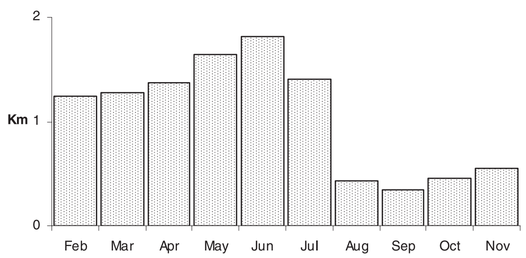

Figure 2: Average per month

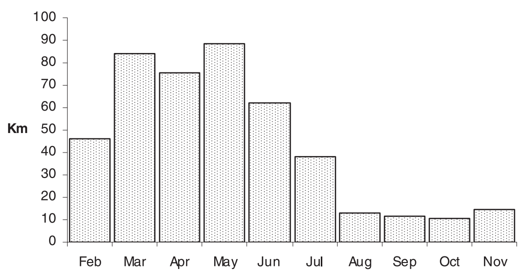

Figure 3: Distances between locations

Table 2. Summary of data received from PTT between 01/08/04 and 31/11/04.

LC	Total Received (equalized n = 8)	Minimum (m)		Maximum (m) With Outliers	Maximum (m) Without Outliers		Outliers
A	87	17		3107	707		4
B	146	99		21,933	9567		6
0	1	1976		1976	1976		0
1	2	121		581	N/A		0
2	8	121		563	N/A		0
3	18	17		228	228		1

provide an idea of the precision of each associated error estimate.

Table 3. Estimates of location class accuracies

LC	Mean (n = 8)	SD (n-1)	95% CI	Points within Buffer (%)
A	154	72	±50	72
B	1860	883	±612	64
2	269	139	±96	71
3	103	44	±30	63

Discussion

Determining time of collar failure

All analysis carried out on satellite-derived data between February and November 2004 indicate that the collar became detached in early August. All subsequent analysis carried out on the PTT-derived data included only data received between February and the 30th of July, 2004, representing around five months of telemetry data.

The large variations in sample size and range between the LCs are, most likely, a result of the way in which the satellite receives and translates the up-links from the PTT. The LC code to which each location is assigned depends, primarily, upon the number of messages received during an overpass by the satellite as well as the distribution of those messages over the time of contact (Argos 1996). For example, an LC 3 code requires at least four equally spaced messages received over a period of no less than seven minutes whilst an LC 0 requires only two messages with no time restrictions (Keating 1994). When considering the role that environmental factors, such as cloud and forest cover, will play in this process, as well as technical considerations such as the path and trajectory of the satellite in relation to the PTT, it is not surprising that "low quality" locations out-number "high-quality" locations. This, alone, is a clear enough indication that those using this system are well advised to calculate their own error estimates before deciding upon the parameters of their final analysis.

Location error estimates

Locations categorized by CLS as belonging to LC 3 proved to be the most accurate and precise of the PTT-derived locations in the current field tests, followed, in order of accuracy, by LC A and LC 2. At the opposite end of the scale, with an estimated error of nearly 2 km, LC B proved far too unreliable for inclusion in subsequent analysis. Although the precision of LC 3 data is in concordance with estimates given by CLS (Table 1) it is interesting to note that here, LC A has proven to be consistently more accurate than LC 2. Disparity between error estimates calculated by the service provider and those determined by the user has, however, been seen before (Minton *et al.* 2003) and, it is assumed, is an example of the case-specificity of the system.

According to CLS, LC A & B data are derived from too few messages (less than four) to allow for error estimates to be calculated (Argos 1996). This can lead the user to assume that they are, inherently, less accurate than those LCs (0-3) that do include an error estimate. As a result, they are often excluded from analysis in favour of LCs 3, 2 & 1 (Tchamba *et al.*

1995; Hays 2001). The results of the current study, however, show that this decision could be misguided and result in the unnecessary reduction of overall sample size possibly at the expense of reliable home range estimates (Harris *et al.* 1990). Indeed, the inclusion of LC A data in the current project led to a doubling of the sample size with home range analysis incorporating only those locations assigned, by CLS, to the Location Classes 3, 2 & A (Goldthorpe & Heffernan in prep.).

Although this test used post-detachment data, which may not always be available to workers, it would be simple to carry out similar tests using PTTs before they are deployed. However, caution should be taken in choosing a suitable area in which to activate and test the transmitter. The performance of the transmitter is affected by many factors ranging from the obvious considerations of, in forest studies, canopy cover and topography to the less obvious factors such as the height of the transmitter from the ground and the speed with which it moves during transmission periods (Sean Walls pers. com.; Colin Hunter pers. com.). For these reasons, the optimal test site would be the study site itself or, at the very least, an area where the environmental and physical conditions most closely match those of the planned study site.

Though it is important to note that the subject animal in the current study had an uncharacteristically small home range (Goldthorpe & Heffernan in prep.), there is no doubt that the ARGOS satellite telemetry system is best suited to studies of wide-ranging animals in relatively open studies. Indeed, the PTTs used by the system are most commonly associated with studying the movements of marine turtles (Kevin Lay pers. com.). For researchers wishing to work with less mobile animals living in an environment where signals may be restricted, however, it may be that a different choice of equipment is required. A good potential alternative uses the already established technology behind the Global Positioning System (GPS) as this has a capacity for a much increased precision and accuracy, over the ARGOS system. There are, of course, still issues presented by, for example, habitat type whereby an extremely dense forest will make communication between the transmitter

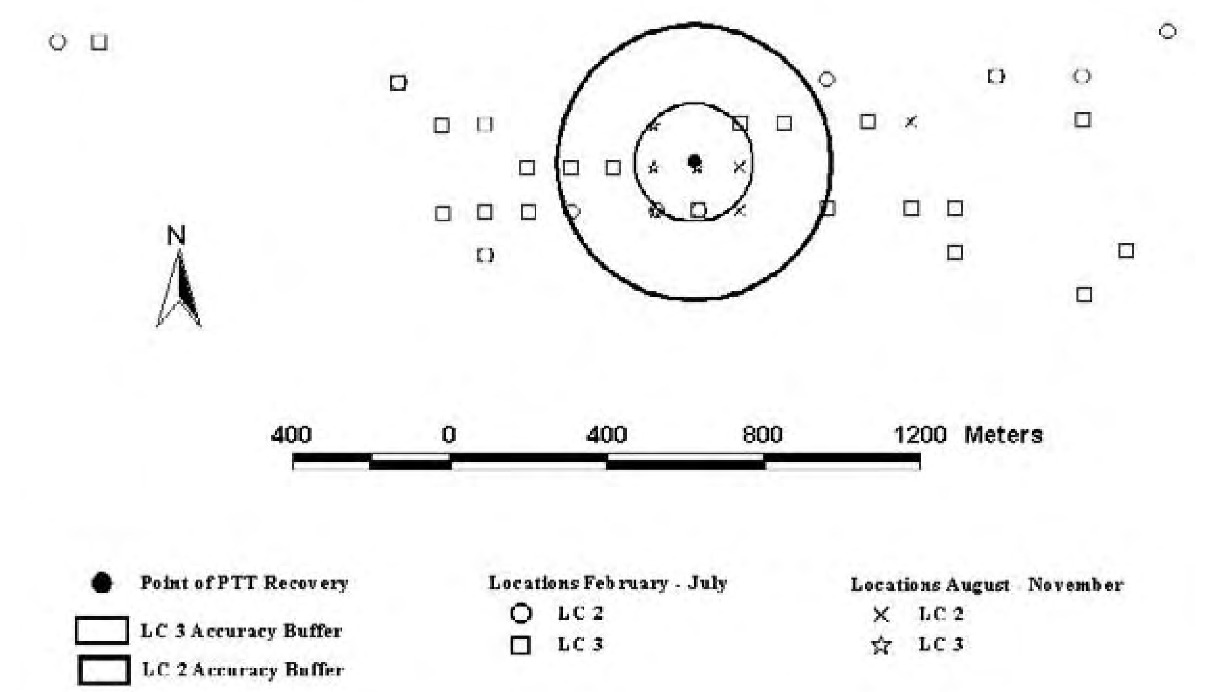

Figure 4: CLS Accuracy buffers around the known location

and receiver difficult but these are issues that are constantly being upgraded and improved.

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Elephant down for collaring
Photo by Gareth Goldthorpe