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SHORT COMMUNICATION

New GPS technology improves fix success for large mammal collars in dense tropical forests

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There have been few telemetry studies on large and medium-sized mammals from Neotropical lowland forests. This can partly be explained by the difficulty of tracking animals with radio-telemetry in these forests, often in remote areas with poor access due to limited transportation infrastructure. Researchers have been forced to follow their collared animals by aeroplane (Crawshaw 1995, Fragoso 1998, Rabinowitz & Nottingham 1986), but aerial telemetry is dangerous and involves difficult logistics and high costs. GPS (Global Positioning System) collars that allow the collection of data automatically at long intervals would be a good alternative. The effect of canopy cover on GPS fix success and location accuracy was of concern from the beginning and has been widely investigated in temperate forests (D'Eon 2003, Di Orio *et al.* 2003, Dussault *et al.* 1999, Moen *et al.* 1996, Rempel *et al.* 1995). All studies found a significant decrease in fix success and a large increase in location errors under forest canopy. Tropical lowland rain forests have a much denser canopy than temperate forests, and up to now the performance of GPS collars in tropical forest has been very poor. Rumiz & Venegas (2006) showed that while GPS collars worked in the dry forest of the Bolivian Chaco, they only obtained a successful fix in 1–3% of all attempts in the lowland forest of the Madidi National Park, Bolivia.

A study on the ecology of lowland tapirs (*Tapirus terrestris* Link, 1795) in the Peruvian Amazon required a system that would work in the dense forest and acquire data with a high temporal resolution. The present study evaluates a new system called TrackTag (NAVSYS Limited, Springwood House, Linburn Rd, Kirknewton, West Lothian EH27 8DY, UK). The TrackTag differs from conventional GPS units used in most animal collars in that it does not perform any data processing at the time of signal acquisition (MacLean 2009). It turns on for 32 ms and during that time records raw GPS signal data. Data are stored in a non-volatile memory and later post-processed on a computer using advanced signal processing algorithms that are able to detect much weaker signals than the algorithms currently used in most GPS units (MacLean 2009). Here I present results on the performance of the TrackTag GPS collars based on data obtained from stationary tests and from four collars deployed on tapirs.

This study was carried out in the Los Amigos Conservation Concession, a 1400-km^2 protected area along the Madre de Dios and the Los Amigos Rivers in the Department of Madre de Dios (12°57′–12°36′ S, 70°02′–70°09′ W, elevations of 250–320 m asl), Peru. Mean annual rainfall is 2500–3500 mm with a marked dry season from June to September. Maximum precipitation falls during the months December to February and mean annual temperature is 24 °C with a minimum of 10 °C and a maximum of 38 °C.

The vegetation is classified as a South-West Amazon moist forest (Olson *et al.* 2001) with three major vegetation types; terra firme forest, floodplain forest and palm swamps dominated by the palm *Mauritia flexuosa*. Terra firme and floodplain forests are mature multi-layered tropical forest with trees reaching over 30 m in height with a canopy cover of 70–100%.

The first collars tested were produced by Advanced Telemetry Systems, Inc. (ATS). They were based on their large-mammal GPS collar (model G2000) with the standard GPS unit replaced by a TrackTag circuit board. In 2006 NAVSYS developed a new fully integrated design (TrackTag electronics, GPS antenna and battery in a waterproof housing) that allowed the attachment of the

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complete assembly to a regular VHF collar. Both designs use the same GPS unit and antenna configuration.

To evaluate the fix success and the error distribution of positions obtained by TrackTag GPS collars under dense vegetation cover, GPS units were set up at a fixed position over a period of 1–2 d and were programmed to attempt a fix every 5 min, resulting in 300–600 fix attempts per site. They were set horizontally at a height of 80 cm above the ground at least 2 m away from the closest tree. For this test 21 different sites were chosen; ten in terra firme forest, nine in floodplain forest and two at locations with a clear view of the sky. All forest sites had a canopy cover larger than 85% and were representing the range of forest structure and tree density found in the area. The exact position of each site was marked with a Trimble GeoXT differential GPS and the data were post-processed to obtain an estimated horizontal position error less than 2.5 m. Tests occurred in October 2006 and between July and August 2007.

During 2005–2006, several lowland tapirs were captured and equipped with TrackTag GPS collars. Some of the collars fell off prematurely, so for this analysis I used data from four collars covering data periods of 23–102 d. Two of the collars were programmed to attempt a fix every 15 min, the other two every 10 min.

The processed data from the GPS units included the following information: fix number, date, time, fix type (3-D, 2-D or no fix), latitude, longitude, altitude, position dilution of precision (PDOP, an indicator for how satellite constellation affects postition accuracy; lower PDOP values indicating a higher accuracy) and satellite vehicle count (SVC, the number of satellites used to calculate the position; more satellites usually result in a higher accuracy). To calculate errors from the true position, coordinates were converted to UTM and then the Euclidian distance to the reference location was calculated. Based on that, the maximum error, as well as different error probabilities, was calculated. Fix success was compared between forest types and between stationary collars and collars on tapirs using a t-test.

Data screening removes large location errors by filtering the data set based on variables such as PDOP or 2-D and 3-D fixes (D'Eon & Delparte 2005, Lewis *et al.* 2007, Moen *et al.* 1997). I evaluated two possible variables that could be used to screen the data; PDOP and SVC, by looking at their correlation with mean location error as well as the percentage of locations with an error >100 m. A variety of different screening options based on minimum SVC, maximum PDOP and a combination of the two were then tried and error percentile, locations with large errors removed and total data reduction were evaluated.

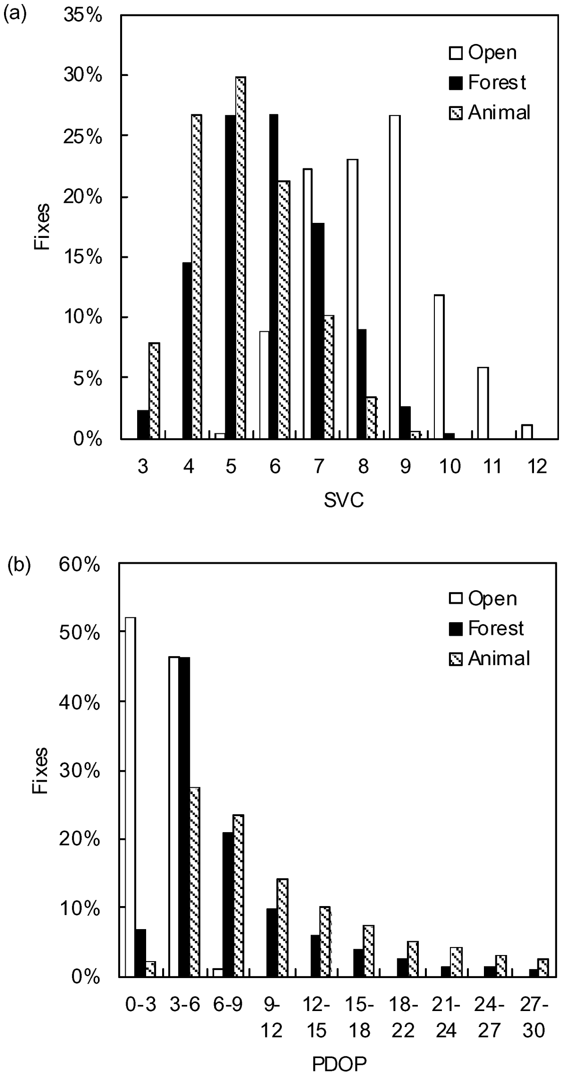

Figure 1. Distribution of the number of satellites used to calculate a position (SVC) (a) and position dilution of precision (PDOP) values (b) for GPS collars placed inside the forest, on free-ranging tapirs (Animal) and in an open clearing in the Peruvian Amazon.

The mean fix success for stationary collars under dense canopy was 87.3% (SD = 6.15%, range = 71.5–94.4%). There was no significant difference between terra firme and floodplain sites (terra firme: 86.0%, floodplain: 88.7%, t = 0.990, df = 11.0, P = 0.343), thus the data from the two forest types were pooled for all following analyses. Fix success for the two open sites was 99.4% and 100%. The mean fix success for the animal collars was 48.5% (SD = 8.54%, range = 38–58%), much lower than for the stationary collars. The mean number of satellites used to calculate a position was significantly lower for collars on animals than for stationary collars (animal: mean ± SD = 5.12 ± 1.26, stationary: 5.82 ± 1.36, t = -38.5, df = 17678, P < 0.0001), and it was lower for both groups compared with collars placed in the open (Figure 1a). Collars placed in the open had more locations in lower PDOP classes than collars placed inside the forest and collars put on tapirs had more locations in larger

Table 1. Data reduction and error percentiles for different data screening options for GPS data from 21 stationary collars as well as from collars put on four tapirs at a forested site in the Peruvian Amazon. Data reduction shows the percentage of data discarded when using a screening option, and values are given for all locations and for locations with an error >100 m and >200 m. Location error indicates the error for stationary collar locations after data screening. Cost is the number of locations with an error <100 m removed for each location with an error >100 m removed. SVC: satellite vehicle count, PDOP: position dilution of precision. *SVC was only filtered for PDOP >10.

	Data reduction (%)					Location error (m)			
Option	All	>100 m	>200 m	Tapir	Cost	50%	95%	99%	100%
All	0	0	0	0	0.0	22	77	146	408
SVC >3	2	18	28	8	5	22	74	136	408
PDOP <21	4	16	28	10	9	21	73	140	408
PDOP <21, SVC >3*	5	28	47	14	7	21	71	131	408
PDOP <21, SVC >4*	11	49	58	27	8	21	66	123	403
SVC >4	17	60	69	35	10	20	63	111	369
PDOP <11	19	55	58	36	12	20	64	121	403
PDOP <7	38	72	72	61	19	20	58	108	369
SVC >5	44	88	97	65	18	19	53	88	317
SVC >6	70	97	100	86	26	18	45	69	133

PDOP classes (Figure 1b). This shows the strong impact canopy cover has on satellite reception.

The location error (mean ± SD) for forest sites was 28.9 (±28.8 m) and was much larger than for open sites (6.7 ± 4.2 m). All locations from the two open sites had an error < 30 m while forested sites had maximum errors of up to 400 m. However, even for forested sites only 2.8% of all locations had an error >100 m. Ninety-five per cent of all locations had an error <76.8 m and 99% had an error <146 m.

Both PDOP and SVC were clearly correlated with mean location error and with number of locations with an error >100 m (Figure 2). The relationship is exponential for SVC and approximately linear for PDOP.

Data screening successfully reduced the number of locations with large errors (Table 1). However this reduction comes at a cost. The lowest filter level (SVC >3) removed about 4.8 locations with an error <100 m for every location with an error >100 m. This value increases linearly with the percentage of high-error locations that are removed and reaches 26.4 at the highest filter level (SVC > 6). Therefore a trade-off exists between removing high-error locations and retaining low-error locations.

The TrackTag GPS collars performed well in all of the tests. Fix success of 70–95% for stationary collars under canopy and 38–58% for collars deployed on animals is comparable to results obtained by conventional GPS collars under the canopy of temperate forests (Frair *et al.* 2004, Lewis *et al.* 2007, Rempel *et al.* 1995, Sager-Fradkin *et al.* 2007). The fix success of the collars deployed on tapirs was markedly lower than the fix success of stationary collars. But this is commonly found with GPS collars (Cargnelutti *et al.* 2007, Lewis *et al.* 2007, Sager-Fradkin *et al.* 2007). While a fix success of about 50% seems relatively low, this is partly compensated by the ability of TrackTags to record a large number of locations. With a typical acquisition interval of 15 min, for a 12-mo deployment, the average number of successful locations

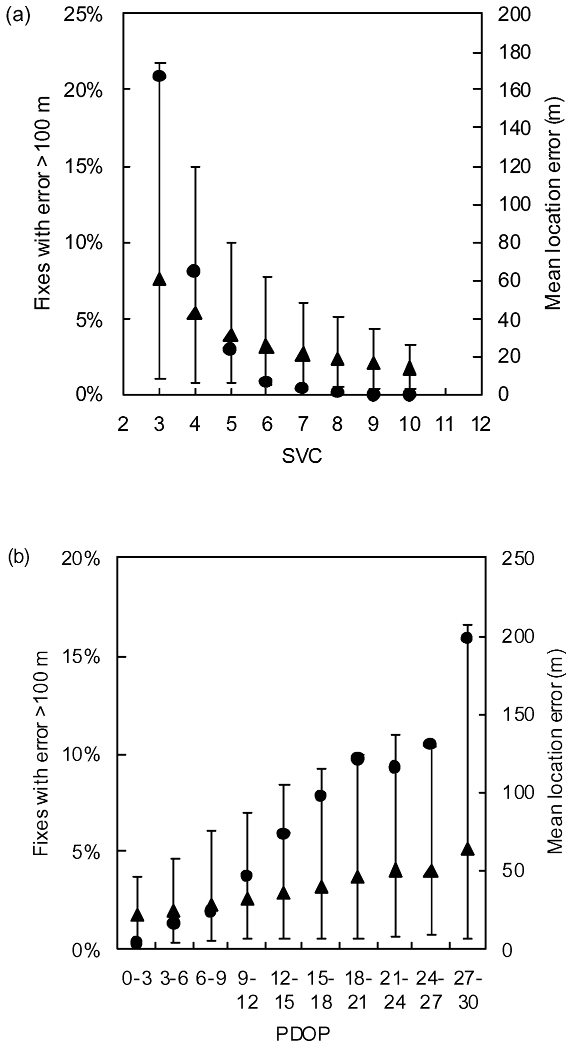

Figure 2. Percentage of locations with an error >100 m (dots) and mean location error (triangles) for different numbers of satellites (SVC) (a) and position dilution of precision (PDOP) values (b). Error bars indicate 5% and 95% percentiles for the location error. The data come from GPS collars placed inside the forest in the Peruvian Amazon.

is 40–50 d^{-1}. This is a huge amount of data that allows researchers to study detailed daily movement patterns. However, the potential bias for habitat studies and home-range estimators introduced by missing data has to be considered in the analysis.

Location errors were significantly larger under dense canopy than in open areas but were within the range of errors reported for other GPS collars in temperate forests (Cargnelutti *et al.* 2007, Lewis *et al.* 2007, Moen *et al.* 1997, Sager-Fradkin *et al.* 2007). There are multiple reasons for an increased error under canopy. Satellite availability is reduced due to blocked signals, there is an increase in multipath (the signal is being reflected by trees or topography causing the signal to travel farther) and the signal-to-noise ratio is lower, making the signal harder to detect. The algorithms used to process the TrackTag data are optimized for detecting weak signals and therefore can increase the number of satellites available compared to conventional GPS receivers. However, the number of satellites is still lower than in the open, and the algorithm cannot remove errors resulting from multipath.

Most previous studies have focused on PDOP or 2-D or 3-D fixes for data screening (D'Eon & Delparte 2005, Dussault *et al.* 2001, Lewis *et al.* 2007, Moen *et al.* 1996). For the datasets presented here results show that data screening based on SVC or a combination of PDOP and SVC is more efficient than screening on PDOP. SVC >3 removes 18% of all high-error locations while only removing 2% of all low-error locations, while screening on PDOP <21 removes 16% of all high-error and 4% of all low-error locations. Screening with the PDOP <21 and SV >3 or PDOP <21 and SV >4 should be most appropriate for these data for most applications. This removed between 28% and 49% of all high-error locations while only removing 5% and 11% of the low-error locations. Data reduction is larger for collars deployed on animals than for stationary collars due to the lager number of locations in lower SVC and higher PDOP classes which are the classes removed by data screening.

TrackTag GPS collars perform well under the dense canopy of an Amazonian forest. Fix success and errors are comparable to data from other GPS collars in temperate forests. This shows that with emerging new technology the use of GPS collars in dense tropical forest becomes feasible, allowing researchers to collect very detailed data on habitat use and movement patterns of elusive species that are hard to follow. A wider use of GPS collars on tropical forest mammals will greatly help in filling important gaps in our knowledge of many species.

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