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Precision and performance of an 180 g solar-powered GPS device for tracking medium to large-bodied terrestrial mammals

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Advances in the technology of biotelemetry are transforming the ways in which we remotely acquire environmental, physiological and behavioural data. Large and heavy batteries, however, continue to reduce the availability of GPS tracking devices for small taxa and for species with morphologies that limit attachment options. Device miniaturisation is beginning to be achieved through the use of in-built solar accumulators, but it is important that the rapid uptake of these technologies does not outpace systematic tests of their precision and performance. Here, we share the technical details of a new 180 g solar-powered device originally designed for vultures but adapted for use on terrestrial herbivores. We test the precision and performance of this device using both stationary and animal-borne trials across multiple geographical areas. Our results show exceptionally high fix acquisition success rates and moderate precision error. We also demonstrate that these solar-powered devices maintain a high and stable voltage over long-term animal-borne trials. These results highlight the importance of a-priori testing of new technologies in biotelemetry research and demonstrate how solar-technology can help to address some of the challenges we face in tracking terrestrial mammals.

Keywords: biotelemetry, miniaturised technology, movement ecology, terrestrial mammals, wildlife tracking

Computational tools and automated methods of ecosystem monitoring are offering unprecedented insights into the natural world (Joppa 2015, Sethi et al. 2018). In the field of movement ecology, biotelemetry, or the remote measurement of state variables of free-living organisms (Cooke et al. 2004), is transforming the ways in which we acquire environmental, physiological and behavioural data (Kays et al. 2015, McGowan et al. 2017). Recent advances allow us to determine near real time positioning with a high level of accuracy and precision for species ranging from honeybees (Kissling et al. 2014) to humpback whales (Garrigue et al. 2015), while integrated biosensors (Tomkiewicz et al. 2010) and a growing array of aerial imaging platforms (Pimm et al. 2015) allow this robust spatiotemporal data to be paired with environmental variables.

To capitalize on such technology, researchers must comply with the animal welfare guidelines that devices weigh no more than 2–5% of an animal's bodyweight (Cooke et al. 2004, Casper 2009). Many biotelemetry devices, however, and particularly those that support remote download GPS capabilities, require cumbersome batteries to support a long operational lifespan (Fischer et al. 2017, Sethi et al. 2018). The size and weight of the battery therefore becomes a limiting factor in research design, with the majority of mammal species still falling outside of the minimum bodyweight bracket for remote download GPS biotelemetry devices (Kays et al. 2015). Furthermore, variation in morphology means that certain species are difficult to tag with cumbersome units, regardless of the size and weight of the animal. In particular, since Adams (1965), most large mammal researchers have opted to use neck collar attachments (suitable for supporting a heavy battery). Some species, however, (e.g. giraffe *Giraffa giraffa*, Fennessy et al. 2016; Fig. 1a–d; and wild boar *Sus scrofa*; Morelle et al. 2014) have unusual neck morphologies that do not easily support a collar type attachment. Research and resultant management implications

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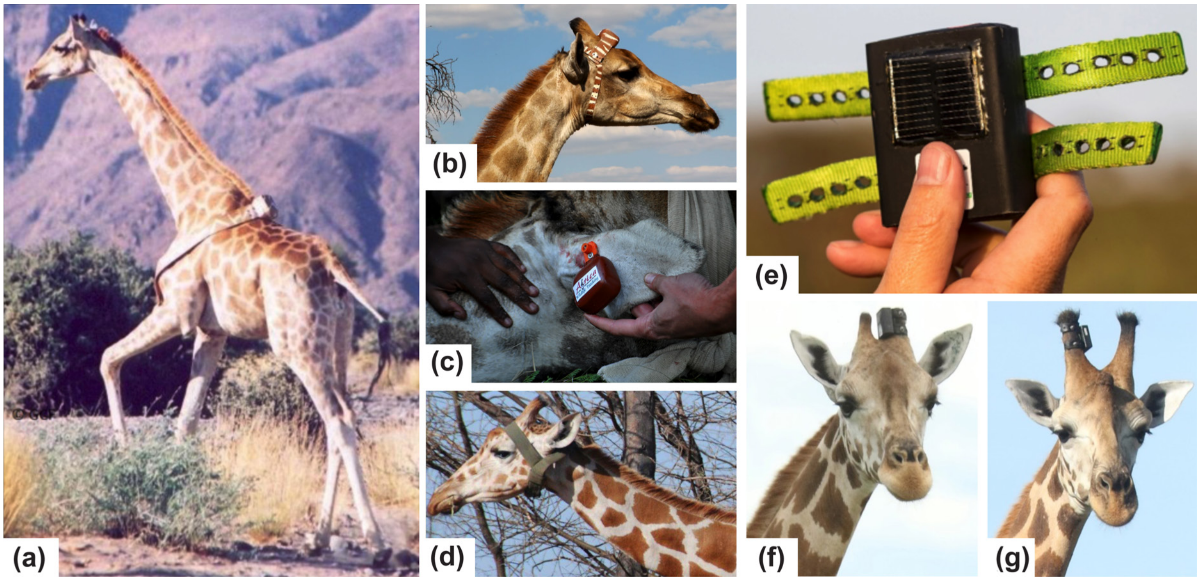

Figure 1. Giraffe are an illustrative case of how reducing the size and weight of devices can open up GPS biotelemetry device attachment options for large mammals: (a–d) attachment options that have proven problematic for giraffe researchers due to the size and weight of the device and (e) the solar-powered device tested here that, due to reduced size and weight, has opened up a new attachment option (on the ossicone; f–g). Specifically photos show giraffe (a) neck collar (Namibia; 2001; © Giraffe Conservation Foundation, GCF), (b) head harness (c) ear tag (South Africa: 2011; © Francois Deacon, University of Free State), (d) head collar (Kenya; © Ian Craig, Northern Rangelands Trust) and (e) 'Ossi-unit' incorporating the solar-powered unit tested here (© Ken Bohn, San Diego Zoo Global) and fitted to the ossicone of (f) a female and (g) a male giraffe (Uganda; © Michae1 Butler Brown).

are therefore likely to be weighted towards large mammals and, within large mammal research, towards those species that have morphologies conducive to attaching a heavy battery. This has the potential to create a systematic bias, particularly considering the rapid expansion of this field (Fraser et al. 2018).

Compromising on battery life to reduce battery size and weight is one way to create smaller, lighter units that have a wider range of attachment options and are therefore suitable for use on a wider range of animals. However, this strategy can also lead to costly tradeoffs. For example, extending battery life by choosing longer intervals between position fixes may limit the inferences that can be drawn from the resulting data (Frair et al. 2010). Similarly, reducing transmission distance by opting for in situ antennae-based download, or daily download to the International Space Station (i.e. the ICARUS system; Curry 2018), can extend battery life but may increase logistical costs or limit the availability of real time position fixes (Fischer et al. 2017). There is therefore still a growing demand for smaller and lighter units that incorporate advanced satellite-based download technology (Kays et al. 2015). Such device miniaturisation is beginning to be achieved through the use of in-built solar accumulators, allowing the size and weight of the devices to be greatly reduced in both biologgers and GPS biotelemetry devices (Geen et al. 2019).

While such developments are opening up attachment possibilities for a wider range of species, there is a danger that the rapid uptake of these technologies could outpace systematic tests of their precision and performance. A lack of a-priori testing of new devices both limits incisive study design and undermines our ability to draw accurate inferences from the resulting data (Frair et al. 2010, Joppa 2015). This in turn reduces both the viability of cross-comparisons and the interoperability of metadata in online repositories (Campbell et al. 2015). As such, while there is an exigent need for the development of smaller, lighter devices, it is also important that the performance of each new technology is tested and the resulting data shared with the scientific community.

Here we present the technical details of a newly developed 180 g solar-powered device, originally designed for vultures, but now adapted for a wide range of large terrestrial mammals, including giraffe (Fig. 1e–g). Using both stationary and animal-borne trials across multiple geographical areas (sensu Jung et al. 2018), we test the performance of the new device on measures of fix acquisition success rate and precision error (two major sources of GPS error; Frair et al. 2010, Jung et al. 2018, Hofman et al. 2019). Furthermore, we test the diel, seasonal and long-term voltage performance of the solar-powered device in an 18-month animal-borne trial on wild giraffe.

Material and methods

Solar-powered device technical details

The GPS devices weighed approximately 180 g and measured 66 × 52 × 23 mm (Fig. 1e–g). The battery system contained a rechargeable $680\,\mathrm{mA\,h^{-1}}$ AA lithium polymer battery, charged by a 33 × 27 mm 4v monocrystalline solar cell capable of providing up to 100 mW. Positioning was based on the GPS with data reporting via the short burst data (SBD) service on the full Earth coverage Iridium network. This allowed for two-way communication and therefore 'on animal' reprogramming of device parameters, including the GPS fix and uploading intervals and the duration of GPS averaging. Battery-voltage and temperature were automatically recorded at each data upload. The device had a cut out voltage level of 3.2 volts, at which it would suspend operations until recharged to avoid damage to the battery.

A 433 MHz UHF telemetry beacon (for back-up localisation), programmable on frequency, output power and time interval, and a 12 bit tri-axial accelerometer (to enable a mortality alarm) were also integrated into the devices. Acceleration data were evaluated in real time on board the devices. This allowed for the mortality alarm to trigger the device to send an automatic GPS location by SMS/email in the case of a lack of movement. Server based geo-fencing analysis could also be activated on predefined points, lines or polygons. The accompanying data management software package allowed for general querying, the addition of auxiliary information and remote downloads in csv, kmz and shp formats. The devices were produced by Savannah Tracking Ltd, Nairobi, Kenya in partnership with the Giraffe Conservation Foundation (GCF).

Data collection

To estimate fix acquisition success rate, precision error and battery voltage, GPS biotelemetry data were collected from a total of fifty individual devices (twenty of which were used in more than one study). Data were collected in five geographical areas between July 2017 and January 2019. The sample sizes varied across measured parameters. All devices were programmed to an inter-fix interval of one-hour and a 10 s GPS averaging period.

Data handling and analyses

Data handling and analyses were performed in R ver. 3.4.2 (<www.r-project.org>). Environmental features for spatial points in the stationary tests were recorded either at the test site (canopy cover, height above the ground, orientation of the unit) or extracted in ArcMap 10.3.1 (slope; ESRI 2014).

Success rate

Fix success rate can be affected by multiple variables including animal behaviour (e.g. standing in the shade), environmental factors (e.g. dense vegetation), satellite coverage (which can vary both by geographical area and time of the day) and battery voltage (due to cut out thresholds). To test the overall fix acquisition success rate of the devices we used data from 35 animal-borne devices fitted to free-roaming giraffe between July 2017 and January 2019 across four geographical areas in Africa (northwest Namibia = 20, northern Kenya = 11, northeast Uganda = 2, central Namibia = 2). Fixes were collected at a predefined (fixed) one-hour interval. The fix success rate was calculated by dividing the number of recorded fixes by the number of scheduled fixes.

Animal-borne devices

To tag giraffe for the animal-borne trials giraffe were darted and immobilized by a registered wildlife veterinarian working alongside an experienced giraffe capture team. Females with a calf and visibly pregnant females were avoided. Giraffe were darted in the shoulder or rump with 100% success rate of administration; there was no need to re-dart any animal and there were no partial drug administrations. After darting, the vehicle remained stationary or kept a distance of ~ 100 m from the giraffe until induction occurred (~ 3–6 min). Once narcotised, giraffe were roped by the capture team and brought to the ground. The antidote was immediately intravenously administered while the giraffe were blindfolded and restrained, after which the devices were fitted. For each giraffe the entire procedure from darting to release took under 30 min. In line with the policy guidelines of the GCF, recapture of giraffe is being undertaken wherever possible to replace or remove failed devices. These modalities were the same for all animals included in the study. The capture methods and veterinary procedures involved are described in detail in Fennessy et al. (2019).

Modelling approach (precision error and voltage)

To model precision error and voltage (full details on model predictors and structure reported below), we used generalised additive mixed models (GAMMs) using the function *gam* from the *mgcv* package in R (Wood 2011). We used smoothing functions to allow for non-linear relationships and cross-validation to automatically determine the optimal amount of smoothing (Wood 2006, 2011). The models were fit using the select = TRUE implementation in the *gam* algorithm of the *mgcv* package, which allowed automated model selection. This option adds a penalty to each smoothing term, allowing it to be penalized out of the model via optimization of the smoothing parameter selection criterion (Wood 2017).

Precision error

To estimate precision error we used data from twenty-five devices deployed in stationary tests in twelve test sites across four geographical areas, with two devices used in multiple test sites (northwest Namibia = 2 devices; central Namibia = 10 devices; northwest Uganda = 10 devices; and northeast Uganda = 5 devices). Each device was deployed for a minimum of one day. We calculated the centroid of all recorded position fixes for each test site and computed the distance between each fix and its corresponding centroid.

To model the effects of environmental variables on precision error, we extracted degrees of slope for the centroid of all fixes for each test site from a 30 m resolution digital elevation model from the RCMRD GeoPortal (as recommended by Jung et al. 2018). The remaining environmental variables were manipulated at each test site. These included canopy cover (with devices either tested in the open or under single trees), height above the ground (with devices 1, 1–1.5 or 2–2.5 m above the ground) and orientation (with devices in either a horizontal or vertical position). These values allowed us to test whether precision was likely to be negatively affected by slope of the terrain, canopy cover, proximity to the ground and/or the possible attachment position of the device (i.e. horizontal or vertical).

We wrote one a priori model structure based on our main set of environmental predictor variables, and included individual device and geographical area as random effects. We screened all candidate predictors for collinearity using a Pearson correlation matrix (Zuur et al. 2009). Height above the ground was collinear ($|r_p| > 0.7$) with both canopy cover and device orientation, leading to an incompatibility in our a priori model. To avoid collinearity issues ($|\mathrm{r_p}| > 0.7$), we wrote two alternative GAMM structures and compared these models using the Akaike information criterium (AIC).

- Model 1 included canopy cover and device orientation as categorical predictors, hour of the day and degrees of slope as smoothing splines, and individual device and geographical area as random effects on the intercept.
- Model 2 included height above the ground (1, 1–1.5 or 2–2.5 m) as a categorical predictor, hour of the day and degrees of slope as smoothing splines, and individual device and geographical area as random effects on the intercept.

A final collinearity screening for each model structure showed all predictor variables had correlation coefficients below the collinearity threshold of $|r_p| < 0.7$ (Zuur et al. 2009). The AIC showed Model 1 to be the superior model, therefore, height above the ground was not retained in the best model.

Equation 1 (describing Model 1) had the following structure:

$$\begin{aligned}&\mathit{Precision\ error}\left(\mathit{log\ transformed}+1\right) \sim \mathit{intercept} + f_1(\text{hour, bs = "cc"})\\&+f_2(\text{device\_id, bs = "re"}) + f_3(\text{degrees\_slope, k = 3}) + \mathit{canopy}\\&+\mathit{orientation} + f_4(\text{geographical\_area, bs = "re"}) + \text{error}\left(\text{Gaussian}\right)\end{aligned}$$

where:

f_n are smoothing functions to allow for non-linear relationships depicting the variation of precision error over time (hour, cyclic cubic regression spline), in relation to degrees of slope (with knots limited to 3 to prevent overfitting), canopy cover (categorical, closed or open) and orientation of the device (categorical, vertical or horizontal), and with the individual device (device_id) and geographical area as random effects on the intercept. The model successfully met the assumptions of constant variance and normality of residuals (Wood 2017) when we log transformed the response variable. Residuals were independent with no trace of spatial or temporal autocorrelations.

Voltage analysis

To investigate the battery life of the solar-powered devices over time, we ran a voltage analysis using data from twenty animal-borne devices fitted to free-roaming giraffe in northwest Namibia from July 2017 to Feb 2019.

To model the effects of environmental variables on voltage levels we used a GAMM (Wood 2006). Battery voltage was expected to vary with Julian day (day of the year; with reduced voltage expected during the winter months due to shorter days), angle of elevation of the sun (diel variation; with reduced voltage expected at night) and days since deployment (battery lifespan; with reduced voltage expected in line with the number of days deployed). Angle of elevation of the sun was extracted using the *oce* package in R (Kelley and Richards 2014, <www.r-project.org>). Individual device was included in the model as a random effect on the intercept. Collinearity screening showed that all predictor variables had correlation coefficients below the threshold of $|r_p| < 0.7$ (Zuur et al. 2009).

Equation 2 (describing Model 3) had the following structure:

$$\begin{aligned}&\mathit{Voltage} \sim \mathit{intercepet} + f_1(\text{sun\_angle}) + f_2(\text{julian\_day, bs = "cc"})\\&+ f_3(\text{days\_deployed}) + f_4(\text{device\_id, bs = "re"}) + \text{error(Gaussian)}\end{aligned}$$

where:

f_n are smoothing functions to allow for non-linear relationships depicting the variation of voltage over time in relation to the angle of the sun, the day of the year and the number of days since deployment, and with individual device (device_id) as a random effect on the intercept. The model successfully met the assumptions of constant variance and normality of residuals (Wood 2017). Residuals were independent with no trace of spatial or temporal autocorrelations.

Results

Success rate

We found a high and consistent fix acquisition success rate of 99.7% (Table 1).

Precision error

Our final dataset comprised 1350 fixes (northwest Namibia = 140; central Namibia = 955; northwest Uganda = 175; and northeast Uganda = 80). Environmental variables included degrees of slope (0–14 degrees, $\bar{x} = 4.09$, SD = 2.29), canopy cover (with 1135 fixes in the open and 215 under tree canopy) and orientation (with 1210 fixes with the device in a horizontal position and 140 fixes with the device in a vertical position). Results of the stationary

Table 1. Fix acquisition success rate of 35 GPS devices trialled on giraffe in four geographical areas in east and southwest Africa between July 2017 and January 2019.

Geographical area	n units	Cumulative n days deployed	Recorded/scheduled fixes	Success rate (%)
NW Namibia	20	4672	111 790/112 128	99.7
Central Namibia	2	336	28 428/28 446	99.9
Northern Kenya	11	347	8297/8300	99.9
NE Uganda	2	57	2696/2748	98.1
Total	35	5412	151 211/151 622	99.7

Table 2. Results of stationary tests for precision error of 25 GPS devices (with two devices used in multiple locations) in four geographical areas in East and southwest Africa between February and June 2018.

Geographical area	n units	n fixes	Precision error (m)			
			Mean	Median	75% Quantile	90% Quantile
NE Uganda	5	80	18.26	17.13	20.4	25.06
NW Uganda	10	175	14.76	12.04	19.98	27.99
NW Namibia	2	140	18.59	12.37	20.14	32.69
Central Namibia	10	955	11.68	7.28	13.07	24.13
Total	27	1350	12.79	8.54	16.61	26.25

tests showed that the devices had moderate overall precision error ($\bar{x}$ = 12.79 m, SD = 16.69 m; Table 2).

Model 1, modelling the effects of environmental variables on precision error, explained 10.2% of the variance. We found a small but significant effect of canopy cover (estimates under tree canopy with open habitat as a reference category: $\beta = 0.192$, SE = 0.092, t = 2.077, $p = 0.038$, Fig. 2) and a significant effect of hour of the day (smoothing spline edf = 5.85, F = 4.93, $p < 0.001$, Fig. 3) but no significant effect of slope of the terrain (smoothing spline edf = 0.4921, F = 0.598, $p = 0.202$) or unit orientation (estimates in a vertical position with horizontal position as reference category: $\beta = -0.184$, SE = 0.465, t = −0.397, $p = 0.692$) on precision error.

Voltage analysis

Results of our voltage analysis, using data from twenty devices fitted to free-roaming giraffe between July 2017 and February 2019 (fixes = 112 408), showed that the voltage remained high across the study ($\bar{x}$ = 4.18 volts, SD = 0.08) never dropping below the cut-out threshold (3.2 volts).

Model 3, modelling the effects of external variables on voltage level, explained 59.4% of the variance. We found small but significant effects for: the number of days the device had been deployed (smoothing spline edf = 8.792, F = 558204.16, $p < 0.001$), with a decrease in voltage (~ 0.2 volts) after 300 days of deployment (Fig. 4a); the angle of elevation of the sun at the time of the fix (smoothing spline edf = 4.843, F = 6.66, $p < 0.001$; with no meaningful effect on voltage; Fig. 4b); and the day of the year (Julian Day, smoothing spline edf = 8, F = 110151.84, $p < 0.001$), with two similarly slight decreases in voltage (< 0.1 volt) which corresponded with the rainy season in NW Namibia in March and April (Julian days 60–120) and with the shorter winter days from May to August (Julian days 120–212; Fig. 4c). Although our model allowed us to explain these slight reductions in voltage, the reductions had little relevance in terms of device functionality; all values fell between 4 and 4.3 volts (a range of 0.3 volts) and never approached the voltage cut out threshold of 3.2 volts (Fig. 4).

Discussion

Results of our stationary tests and animal-borne trials showed that the 180 g solar-powered GPS biotelemetry devices had an exceptionally high fix acquisition success rate and moderate precision error. Our results also demonstrated that the devices retained high and stable voltage across long-term animal-borne trials.

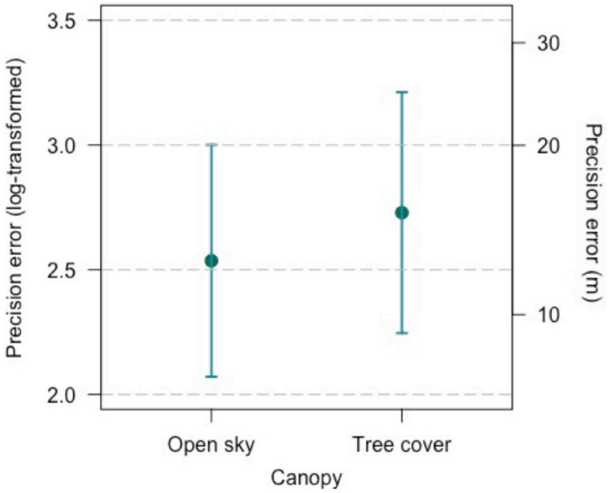

Figure 2. Effect of canopy cover on precision error from 1350 fixes (1135 open sky, 215 tree cover; 1210 horizontal; 140 vertical) collected from 25 GPS devices (with two units used in multiple locations) in four geographical areas in East and southwest Africa between February and June 2018, with point wise 95% confidence intervals for the fitted generalized additive mixed model (GAMM).

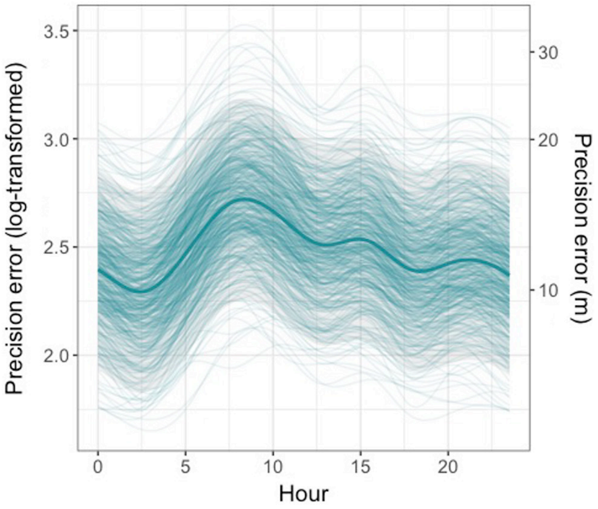

Figure 3. Effect of hour of the day on precision error from 1350 fixes collected from 25 GPS devices (with two units used in multiple locations) in four geographical areas in East and southwest Africa between February and June 2018, with point wise 95% confidence intervals for the fitted generalized additive mixed model (GAMM). Each line is one of 500 draws from the Bayesian posterior distribution of the model.

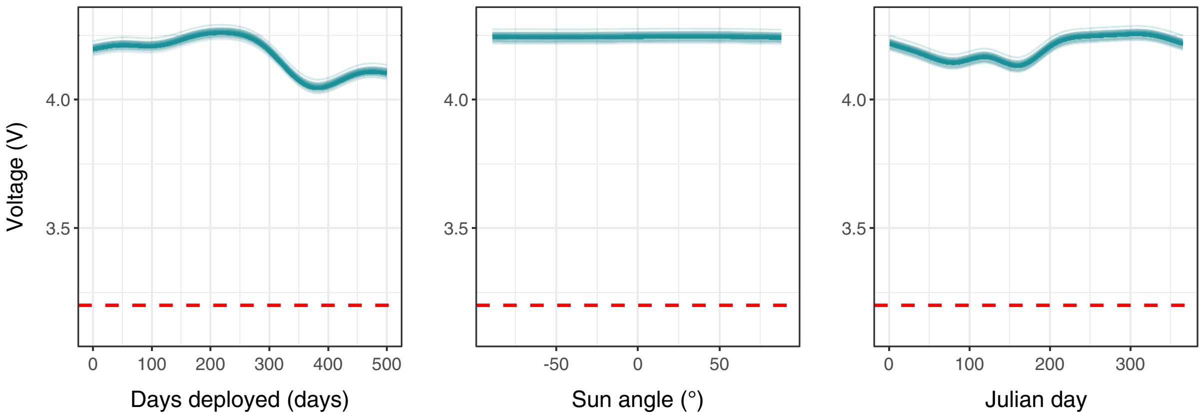

Figure 4. Effect of (a) the number of days of deployment, (b) the degrees of elevation of the sun (sun angle; with 0 degrees corresponding to sunrise/sunset) and (c) the day of the year (Julian day; with the rainy season ~ days 60–120, and shorter winter ~ days 120–210), on the voltage profile extracted from 112, 408 fixes from 20 devices fitted to free-roaming Angolan giraffe in NW Namibia from June 2017 to January 2019. The plots show point wise 95% confidence intervals for the fitted generalized additive mixed model (GAMM), and each line is one of 50 draws from the Bayesian posterior distribution of the model. The horizontal dashed line marks the voltage cut out threshold of 3.2 volts.

Our measures of fix acquisition success rate (99.7%) from animal-borne trials compare favourably with those of other studies. In a recent review, Hofman et al. (2019) reported an overall fix acquisition success rate of 78% across 167 studies of GPS biotelemetry in terrestrial wildlife research. Our measure of precision error ($\overline{x} = 12.79$ m) from stationary tests is moderate. Jung et al. (2018) for example report a mean 4.3 m precision error on stationary tests of GPS collars designed for bison *Bison bison* and caribou *Rangifer tarandus*. However, Jung et al. (2018) used an inter-fix interval of 24 h in comparison to our 1 h inter-fix interval, and also report an average of 5–20 m accuracy across the literature on stationary trials of biotelemetry devices for terrestrial mammals. In terms of the effects of environmental variables on precision, we found that precision error was slightly higher in the morning, likely due to variation in satellite coverage across the diel cycle. In line with Jung et al. (2018), there was also a significant but weak effect of canopy cover, with a trend towards increased error when the test site was under the canopy of a single tree. Slope of terrain (0–14°) and unit orientation (90 or 180°) did not have significant effects on precision error.

Results of our voltage analysis showed that although significant, variation in voltage level in line with the angle of elevation of the sun did not have a meaningful effect on the functionality of the units. This suggests that, once charged, the units maintained high voltage throughout periods of little or no solar energy (i.e. when animals were standing in the shade, or during the night). We also found little seasonal variation; although day of the year was statistically significant, the size of the effect was very small, with a negligible dip in voltage corresponding to the wet season (cloudier) and winter days (reduced hours of daylight). A limitation of our study was that our voltage trials were restricted to field trials in Namibia, which is characterised by high availability of daytime solar energy (Maúre et al. 2018). Further research is necessary to determine whether the solar accumulator is as efficient in climates characterised by lower availability of daytime solar energy. However, preliminary results from animal-borne trials in the USA and Canada (on a variety of large mammals; Fig. 5) are showing that devices retain a similarly high and consistent voltage charge across northern hemisphere latitudes, and are expected to function within a charging temperature range of −45° to +85°C (Smithsonian Conservation Biology Institute (SCBI); Savannah Tracking Ltd., unpubl.).

In terms of functional longevity, our results showed a very slight dip in voltage level (< 0.2 volts) after approximately 300 days of deployment, possibly signalling a minor reduction in battery system efficiency. However, at no point across the 18 months of the study did the voltage level approach the cut out threshold of 3.2 volts, nor did any of the devices in this study fail prematurely due to other technical issues. Such low failure rates compare favourably with the 48% failure rate for GPS biotelemetry devices in terrestrial wildlife research as reviewed by Hofman et al. (2019).

Since our trials, the battery system of the units tested here has been upgraded (to a Tadiran 150 mA h^{-1} ⅔ AA sized lithium ion battery with a charge cycle performance of 5000+ recharging cycles; <https://tadiranbatteries.de>). This has allowed for a further reduction in unit size (65 × 37 × 32 mm) and weight (100 g). While this weight still precludes many small terrestrial mammals (Cooke et al. 2004, Casper 2009, Kays et al. 2015), these solar-powered devices do open up possibilities for tracking terrestrial species weighing ~5–10 kg or above and that are active (at least in part) during daylight.

It was beyond the scope of this study to run trials on the upgraded battery system; however, it is expected that upgraded units will outperform the units tested here in terms of functional longevity. The upgraded system is also expected to have the capability to record hourly fixes for six days without any power input (Savannah Tracking, unpubl.) making the devices more suitable for species inhabiting environments with lower availability of daytime solar energy. Furthermore, there is an option to combine a solar accumulator (as tested here) with a primary battery, potentially extending the lifespan of devices where solar charging opportunities are limited by environmental conditions (e.g. closed canopies) or species-specific behaviour (e.g. crepuscularity).

Figure 5. Trials of the solar-powered device showing a range of attachment types across taxa including (a) giraffe – ossicone, (b) scimitar horned oryx – horn (© John McEvoy/SCBI), (c) Przewalski's stallion – tail hair (© John McEvoy/SCBI), (d) elephant calf – collar (© David Daballen) and (e) Rüppell's vulture – 'backpack' (© Laila Bahaa-el-din; inset: Henrik Rasmussen).

The past two decades have illustrated how technological advances can provide new insights into the behavioural and ecological correlates of life history events for a wide range of species, for example migration (Juang et al. 2002), social interaction (Farine et al. 2017, Papageorgiou et al. 2019), mortality (Collins and Kays 2011) and dispersion (Killeen et al. 2014), as well as personality and individual differences (Hertel et al. 2019). We expect that advances in the functional longevity of tracking devices such as those presented here will open up unprecedented possibilities over the coming decade, ultimately allowing us to remotely gather information on animals across their entire lifespans. Such advances in functional longevity will have clear animal welfare implications in terms of the cost–benefit balance in animal tracking ethics (Kays et al. 2015). In particular, while it is clear that the minimum number of animals should always be tagged to fulfil the requirements of robust a priori study designs (Cooke et al. 2004, McGowan et al. 2017, Geen et al. 2019), devices with longer lifespans will potentially lead to a greater quantity and quality of data collected per individual captured as well as to a reduced frequency of recaptures for removal or replacement of failed devices.

To conclude, we have shared the technical details and capacity of a new solar-powered biotelemetry device originally designed for vultures, adapted for giraffe and now being field-tested on a range of species using a variety of methods of attachment (Fig. 5). Future trials using larger sample sizes over a broader range of conditions for each variable would be a useful next step in terms of understanding the precision and accuracy of this device in less favourable environments (e.g. under closed canopies and on steep mountainous terrain; Jung et al. 2018). As ever-increasing restrictions on the free-movement of wildlife (Tucker 2018) underline the importance of acquiring accurate baseline data to inform conservation management strategies (Fraser et al. 2018), we urge that wildlife researchers share data on the performance of new biotelemetry devices wherever possible in order that we might best capitalise on rapid technological advances.

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Author contributions – EH and SC designed the study, analysed the data and drafted the manuscript. JF and HR trialled and developed the hardware and EH, AM, MB-B and JF collected the data.

Conflicts of interest – Dr. H. Rasmussen provided the technical details of the devices tested in this paper and therefore has been included as a co-author. The devices tested here were produced by Dr. Rasmussen at Savannah Tracking Ltd.

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