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TECHNICAL REPORT

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First known satellite collaring of a viverrid species: preliminary performance and implications of GPS tracking Malay civets (*Viverra tangalunga*)

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Abstract The application of advanced technologies to the study of little-known species is a necessary step in generating effective conservation strategies. Despite the biological importance of the small carnivore guild, a paucity of data exists in terms of the spatial ecology of these species, largely due to logistical constraints of large and bulky collar units. This study reports the first known satellite collaring of a viverrid, the Malay civet (*Viverra tangalunga*), in Sabah, Malaysian Borneo. Stationary tests of two generations of 65–70 g e-obs GmbH 'Collar 1A' units recorded high fix success rates and good accuracy and precision under semi-open canopy. From October 2013–August 2015, nine adult *V. tangalunga* were fit with e-obs collars recording hourly nocturnal GPS locations. Collars were successfully deployed for 27–187 days. Field GPS fix success varied from 22 to 88.3 %, with the study documenting a total GPS success of 58.1 % across all individuals. Despite this large in-field performance range, the quality and quantity of data collected by these units surpass that of previous VHF studies on Asian viverrids, collecting on average a 16-fold increase in locations per collaring day. The successful application of satellite technology to these little-known carnivores carries significant biological and conservation implications, and it is recommended that satellite collars are a viable technology to conduct detailed and well-designed ecological studies of Viverridae species.

Keywords GPS collar · Satellite · Viverridae · *Viverra tangalunga* · Spatial ecology

Introduction

Global biodiversity loss is progressing at increasingly alarming rates (Schipper et al. 2008; Barnosky et al. 2011; Ceballos et al. 2015; Ripple et al. 2015). To mitigate further loss, effective conservation management plans are critical, which in turn require in-depth understandings of species' biological requirements (Margules and Pressey 2000; Chetkiewicz et al. 2006; Cooke 2008). Documenting and quantifying factors crucial to species survival are the central aims of applied wildlife research, and the design of innovative research tools facilitates the achievement of these goals.

Remote tracking technologies in wildlife studies have revolutionized scientific understanding of animal behavioural patterns and processes (Cooke et al. 2004; Ropert-Coudert and Wilson 2005; Fuller and Fuller 2012). The application of radio telemetry as very high frequency (VHF) collar transmitters allowed for the first remote documentation of animal movements in the 1960s (Craighead et al. 1963). While revolutionary, VHF tracking often requires significant field effort for sparse and relatively inaccurate data (Recio et al. 2011a; Gitzen et al. 2013). Furthermore, the collection, applicability, and quality of VHF data are limited by intrinsic biases such as observer presence, site remoteness, weather, and specific animal behaviours (Fuller et al. 2005; Recio et al. 2011b).

In response to these limitations, satellite-based tracking technologies, such as the global positioning system (GPS), were first applied to wildlife in the 1970s (Craighead et al. 1972). This development meant the collection of larger, more consistent, fine-scaled and

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accurate datasets (Rodgers 2001; Kochanny et al. 2002). Satellite tracking minimizes logistical effort and eliminates the influence of observer presence on recorded behavioural patterns, generating datasets otherwise unobtainable by VHF tracking and more relevant to conservation actions (Hebblewhite and Haydon 2010). Satellite collars have established habitat utilisation and preferences for wary and remote species (Amstrup et al. 2004; Simcharoen et al. 2014), uncovered areas of previously unknown reproductive significance in widely migrating species (Lindsell et al. 2009; Schofield et al. 2009; Hays et al. 2014), and discovered novel cryptic behaviours (Davis et al. 1999; Bandeira de Melo et al. 2007; Lührs and Kappeler 2013).

However, the universal application of GPS to wildlife tracking is still limited by technological constraints, as historically, both transmitters and batteries have been bulky and large (>400 g, some up to 2.2 kg) (Rodgers 2001). Most terrestrial GPS studies have focused on mammals >7 kg, so spatial research on small and medium-sized species relies on VHF transmitters (Blackie 2010; Cagnacci et al. 2010). Owing to recent advancements in both battery longevity and the miniaturization of GPS component design, long-term satellite technologies are being applied to increasingly smaller mammalian species, such as the ocelot *Leopardus pardalis* (Haines et al. 2006), European hedgehog *Erinaceus europaeus* (Recio et al. 2011c), fossa *Cryptoprocta ferox* (Lührs and Kappeler 2013), fisher *Martes pennanti* (Brown et al. 2012), and brushtail possum *Trichosurus vulpecula* (Blackie 2010; Dennis et al. 2010).

The Viverridae family (Order Carnivora) comprises 34 species in 14 genera, the majority of which weigh <8 kg (Jennings and Veron 2009). There exists a significant paucity of data concerning even basic ecological information of this family (Schreiber et al. 1989), and five viverrid species are not yet represented in peer-reviewed literature (Brooke et al. 2014*)*. What studies do occur are dominated by camera trap deployments (Wilting et al. 2010; Jennings et al. 2015), survey transects (Heydon and Bulloh 1996; Iseborn et al. 2010), and a handful of VHF studies (Joshi et al. 1995; Grassman 1998; Grassman et al. 2005a; Berhanu et al. 2013; Camps and Alldredge 2013; Nakashima et al. 2013). Viverrids are threatened by habitat loss and hunting, but also by lack of scientific information regarding rudimentary survival parameters (Schipper et al. 2008; Brooke et al. 2014). This knowledge gap poses a substantial threat to the effective conservation and management of these species.

Therefore, this study sought to demonstrate the applicability, performance, and value of satellite tracking a model viverrid, the Malay civet (*Viverra tangalunga*). Weighing between 3–7 kg, *V. tangalunga* is a predominantly solitary and terrestrial small carnivore found throughout the Sundaic region of Southeast Asia (Payne and Francis 1985). Although several VHF studies have evaluated the spatial ecology of *V. tangalunga* (Nozaki et al. 1994; Colón 2002; Jennings et al. 2006, 2010), this study represents the first known application of GPS collars to the Viverridae family, and ultimately aimed to demonstrate the scientific and conservation value of GPS technology deployments on small carnivores.

Methods

Study site

The Lower Kinabatangan Floodplain is located in eastern Sabah, Malaysian Borneo (approximate range: 5°18′N to 5°42′N and 117°54′E to 118°33′E). The climate is humid tropical with temperatures ranging from 21 to 34 °C (Ancrenaz et al. 2004). This study was based in the Lower Kinabatangan Wildlife Sanctuary (LKWS), a 270 km^2 area of protected secondary forest flanking the Kinabatangan River (Ancrenaz et al. 2004; Goossens et al. 2005). Comprised of ten riparian lots of varying degrees of disturbance history, the sanctuary contains a mixture of dry lowland, semi-inundated, and swamp forests interspersed with small grasslands (Abram et al. 2014).

Trapping and immobilization

Trapping periods spanned October 2013–August 2015. Small carnivores were trapped using locally constructed, specially designed box treadle traps (110 cm × 35 cm × 40 cm). Traps were set by 18h00, checked between 07h00 and 08h00, and closed during the day to avoid non-target diurnal captures.

Upon capture, animals were administered anesthesia by a qualified veterinarian. Animals were either sedated with Tiletamine/Zolazepam (Zoletil™, Virbac Laboratories, Carros, France), or a mixture of Ketamine (Narketan™, Vétoquinol UK Limited, Buckingham, UK), Xylazine (Ilium Xylazil™, Troy Laboratories PTY Limited, Glendenning, Australia) and Tiletamine/Zolazepam. In the case of the latter drug combination, the reversal agent Yohimbine (Reverzine™, Bomac Pty Limited, Hornsby, Australia) was administered once sampling was complete.

GPS collaring and tracking

GPS collars (Collar 1A and second-generation Collar 1A, e-obs GmbH, Grünwald, Germany) weighed 65–70 g, or between 1.3–1.4 % of average adult civet body weight, well within the restrictions of the American Mammal Society for the ethical collaring of animals (Sikes and Gannon 2011). Each tag contained a GPS microchip, either a 2300 or 2500 mAh battery, UHF radiotransmitter, a tri-axial accelerometer, and an antenna. The collar was constructed to degrade through a thin section of leather near the fastening, and efforts were made to retrieve the collar following the cessation of data collection.

Civets are nocturnal, and utilize day bed resting sites in dense forest or grassy areas (Colón 2002; Jennings et al. 2006). To conserve tag battery life and obtain the highest resolution of relevant GPS fixes, collars were set to record 13 hourly GPS points from 18h00 until 06h00. Collars were programmed with a 150 s 'GPS timeout', whereby the unit would cease searching for available satellites if no successful fix was acquired within this limit. For each successful GPS point, the collar recorded longitude, latitude, date, time, time to first fix, battery voltage, temperature, speed estimate, and heading.

Due to the small size of the tags, a remote ultra-high frequency (UHF) download was required to access GPS and activity sensor data. A hand-held device (BaseStation II, e-obs GmbH) needed to be within transmittable range of a tagged individual, following which a high-speed wireless radio-link would be established and logged data downloaded to the BaseStation.

Collars emitted a UHF radio signal for two and a half hours daily to allow for tracking. Collared individuals were tracked using a UHF 7E 868 MHz Yagiantenna (e-obs GmbH), an AOR AR8200 handscanner radio receiver (AOR Ltd, Tokyo, Japan), and the BaseStation. For most data download events, animals were tracked via the UHF pinger until adequate tag proximity (~50–150 m) was reached for data download to commence.

Data extraction occurred through the use of DataDecoder software v5_1s6 and v7_1 (e-obs GmbH), which converted encrypted BaseStation data into a desired file format. These were imported into MS Excel and ArcGIS 10.1 for subsequent analysis.

Collar stationary performance

Prior to deployment, three first-generation and four second-generation collars were tested at a stationary reference point under semi-closed canopy for a 13-h nocturnal period. Collar performance was determined by proportion of successful fix attempts. Accuracy was measured as Euclidean distance between collar fixes and the unit's true location, as recorded by a GPSmap 62 GPS (Garmin Ltd., Kansas, USA). The precision of fixes was evaluated by measuring the Euclidean inter-point distances between each collar's hourly fixes. Each collar's maximum linear error was determined as the greatest inter-point distance, representing effective point spread, collected throughout this trial period.

Analysis

All spatial analyses were carried out with ArcGIS software (Version 10.1, ESRI, Inc., Redlands, CA). In stationary accuracy tests, data were log transformed for normality, and a pooled, two-tailed, two-sample t test was used to evaluate if linear error differed by collar generation. A Mann–Whitney U-test determined whether linear inter-point differences differed by collar generation. Maximum inter-point distances between generations were tested by a pooled, two-tailed, two-sample t-test. For field-deployed collar data, in-field performance values were pooled regardless of collar generation. In order to quantify tracking data resolution per collaring effort, a mean value of location fixes per active collaring day was calculated for this study and other viverrid VHF research. The total number of successfully recorded locations was divided by the maximum active collaring days for each animal in each study, and a two-tailed, two-sample t-test compared the log-transformed mean fix values between GPS and VHF studies.

Results

Trapping

From October 2013–August 2015, 731 trap nights (night × number of active traps) were conducted throughout the LKWS, resulting in 43 small carnivore captures (5.9 % trapping success rate). Of these, 27 unique Malay civets were captured, and nine of these individuals collared (eight males, one female).

Collar stationary performance

Of the collars tested, fix success was high and location error slight, with second-generation collars outperforming first in most parameters. First-generation units demonstrated a mean (±SE) fix success of 87.2 % ± 5.13 ($n = 39$), while second-generation collars obtained all attempted fixes ($n = 50$).

In terms of collar accuracy, mean (±SE) Euclidean distance error between GPS fixes and true location was 21.0 m ± 2.60 for first-generation units ($n = 34$). Second-generation collars displayed a significantly lower mean horizontal distance error of 12.3 m ± 1.87, nearly half as large as that of the first-generation units ($n = 50$) ($t = 3.9225$, d.f. = 82, $P < 0.001$). Collar precision improved between first- ($n = 177$) and second-generation units ($n = 288$), with each collecting median inter-point distances of 19.65 m and 12.67 m, respectively ($U = 33749$, $P < 0.01e-6$). However, the mean (±SE) maximum linear point spread of first-generation collars [75.9 m ± 17.7 ($n = 3$)] did not significantly vary from that recorded by second-generation units [53.3 m ± 14.7 ($n = 4$), $t = 0.9926$, d.f. = 5, $P = 0.3665$].

Collar field performance

From October 2013–August 2015, nine Malay civets (eight males and one female) were fit with GPS collars.

Table 1 Collaring details and performance indices for seven male Malay civets tracked in the Lower Kinabatangan Wildlife Sanctuary in 2013–2015

ID	Mass (kg)	Collaring date	Collar generation	Total nights tracked	Total successful GPS fixes	Fix success (%)
Male 1	5.5	27 October 2013	1	187	1990	81.9
Male 2	4.5	3 November 2013	1	37	329	68.3
Male 3	4.3	5 April 2014	1	130	438	26.0
Male 4	5.3	7 April 2014	1	119	339	22.0
Male 6	5.3	6 April 2015	2	27	310	88.3
Male 7	5.0	5 August 2015	2	77*	747*	74.5*
Male 8	4.3	8 August 2015	2	74*	758*	78.7*

* As of October 2015

Table 2 Collar performance and data value [mean ± standard error (SE) of locations per collaring day] of Asian viverrid spatial ecology studies

Species	Collar type	No. successfully collared animals	Mean (±SE) locations per collaring day	Min–max tracking duration (days)	Study
Viverra tangalunga	GPS/UHF	7*	8.1 ± 1.7*	27*–187	Current
Viverra tangalunga	VHF	12	0.4 ± 0.09	138–410	Colón 2002
Viverra tangalunga	VHF	7	0.3 ± 0.07	6–59	Jennings et al. 2010
Paradoxurus hermaphroditus	VHF	12	0.6 ± 0.08	133–670	Nakashima et al. 2013

* As of October 2015

Data were successfully retrieved from seven of these nine individuals (Table 1). Four animals were recaptured following completion of the data collection period, and no change was documented in body condition or weight, although minor hair loss was noted.

In total, 8,450 GPS fixes were attempted by all collars, with 4906 successfully obtaining latitude and longitude, a total fix success of 58.1 %, with individual collar performances ranging from 22.0 to 88.3 %. Collar longevity reached a maximum of 187 days before battery exhaustion. The shortest complete deployment occurred when a collar was prematurely shed after 27 nights of data collection.

Collars collected a mean (±SE) 8.1 ± 1.7 fix locations per active collaring day, representing a significantly greater maximum data resolution than of that collected by VHF studies on Asian viverrids (Table 2; t = 11.604, d.f. = 36, $P < 0.01e\text{-}10$).

Discussion

The recent downsizing of satellite tracking technologies has allowed a greater diversity of species to be collared with the aim of providing accurate and high-resolution spatiotemporal data. This study demonstrated the successful preliminary performance of small satellite collars, both in stationary tests and deployed upon a novel small carnivore, the Malay civet.

Stationary test performance parameters of both first- and second-generation collars were comparable to the high fix success rates, accuracy, and precision values of other small satellite unit performance studies (Cain et al. 2005; Jiang et al. 2008; Dennis et al. 2010; LaPoint et al. 2013). The error associated with triangulation-based VHF tracking can be upwards of 200 m, so this slight GPS error is of little comparative consequence (Grassman et al. 2005b; Bartolommei et al. 2012; Nakashima et al. 2013). These stationary trials demonstrate the much higher quality of GPS compared to VHF data in small carnivore research.

This study reports the first known satellite collaring of a Viverridae species. Overall fix success rate was similar to the performances of other small, field-deployed GPS units (Haines et al. 2006; Blackie 2010; Recio et al. 2010; Brown et al. 2012). Large variability of GPS fix success rates between tracked individuals (22.0–88.3 %) is a commonly documented trend in satellite tracking, and could be attributed to the specific behaviours of collared animals (Blackie 2010; Mattisson et al. 2010; Recio et al. 2011a). Collar-bearing civets utilised a range of microhabitat types, with some individuals (Males 3, 4, 6–8) residing in areas of greater undergrowth and canopy densities than others (Males 1, 2). These environmental factors can influence fix success rates, and should be taken into consideration when designing and analyzing studies on tropical terrestrial species (Rempel et al. 1995; Mattisson et al. 2010; Gitzen et al. 2013).

The volume and fine-scale spatiotemporal resolution of data collected by satellite collars exceeded that of Asian VHF-based Viverridae studies, with satellite units collecting, on average, more than 16-times more locations per sampling day than traditional radio-telemetry methods. This increased data resolution allows for more biologically rigorous questions to be answered on wary and cryptic species in demanding field conditions, without the negative effects of VHF observer bias, and for significantly less effort per resultant fix. Positive results from this first civet GPS collaring, along with the high quality and resolution of stationary trial data, confirms this method as a strong alternative to traditional VHF telemetry tracking for small carnivore research.

Despite these successful first deployments, it is of value to note a design limitation with this brand of satellite units. There is currently no standardized internal calibration value of GPS fix quality in these collars, such as a dilution of precision (DOP), a common component of most unit design. These values facilitate the development of post hoc data screening protocols in order to increase the biological relevancy of acquired GPS data (Lewis et al. 2007; Frair et al. 2010).

Study designs must carefully consider the objectives of their research before deciding upon the deployment of satellite units, as several shortcomings must be overcome before the technology becomes a standard method in small carnivore research (Cooke 2008). While collars utilised in this study are currently the smallest known mammalian long-term GPS units, 65 g is still much too large for certain species. For those species large enough to bear a tag, battery life can be an issue, such that long-term behavioural patterns are unable to be determined. The balance between data resolution and study longevity must be considered when planning studies (Kochanny et al. 2002; Land et al. 2006; Tomkiewicz et al. 2010).

Furthermore, GPS hardware is currently more expensive than VHF transmitters (Rodgers 2001). This high initial cost can pose a logistical barrier to projects, and researchers must not sacrifice statistical power in the blind pursuit of advanced techniques. Many scientists discuss that for certain research questions, analytical rigor is strengthened more so by an increase in the number of individuals tracked than by the number of locations per animal (Hebblewhite and Haydon 2010). Researchers must then carefully consider their specific study aims, budget, focal species, and working conditions to strike a balance between the deployment of several expensive GPS units vs. a larger number of VHF collars, as this study demonstrated. Additionally, when GPS collar failures do occur, they are considerably more costly in both value and relative data loss than VHF failures. A large amount of GPS collar failures have been documented in field-deployed scenarios (Blake et al. 2001; Johnson et al. 2002; Gau et al. 2004; Hebblewhite et al. 2007; Blackie 2010). In this study alone, 22 % (n = 2) of deployed GPS collars failed. Research must then be further prepared to accommodate the costs, both monetary and scientific, of such occurrences with robust study designs.

Despite these considerations, the resolution and quality of GPS data remain irrefutable advantages of the technology. This study highlights the value of GPS collars for small carnivore research due to the data accuracy, quantity and quality otherwise unobtainable in this study area with alternative methods such as VHF or camera trap surveys. The successful application of GPS collars to *V. tangalunga* generated a large dataset of fine-scale spatiotemporal information useful for identifying landscape features important for the persistence of small tropical carnivores. This information can begin to fill the knowledge gaps currently afflicting the guild, such that informed and effective conservation management plans might be drafted. Given a well-crafted study and sufficient funds, small carnivore scientists can utilize satellite technologies to explore the next frontier in understanding and conserving this unique guild.

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