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Monitoring tropical forest ungulates using camera-trap data

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Abstract

Tropical forest ungulates are poorly known and, despite their ecological and conservation significance, there are few studies on their density and abundance. I estimated densities of lesser oriental chevrotain *Tragulus kanchil* in the Southern Cardamom National Park, south-west Cambodia using camera-trap encounter rates and fitting a random encounter model (REM) that does not require individual identification of animals. This represents the first use of REM on forest ungulates in mainland tropical Asia and provides the first density estimate for any chevrotain species in mainland South East Asia. Sixty-five camera-trap stations generated 501 encounters of lesser oriental chevrotain across >8200 camera-trap nights within a systematic random camera-trap grid of 200 km^2 in the Southern Cardamom National Park. Density of lesser oriental chevrotain was estimated at between 57 and 98 ($\bar{X}$ 81) individuals per km^2. The random deployment of camera-traps, a prerequisite of the REM, did not prevent the detection of the majority of ground-dwelling large mammal species likely to be present in the study site. Despite its slow uptake by field conservationists, the REM may have potential for monitoring tropical ungulates particularly in dense evergreen forest where other methodologies, for example, distance-based line transect sampling are unsuitable.

Introduction

The natural history and conservation needs of many tropical forest ungulates are poorly known despite the important functional roles of such species in ecosystems, such as seed dispersal (Foster, Barton & Lindenmayer, 2014), structuring vegetation through herbivory (Augustine & McNaughton, 1998), and as prey for medium to large carnivores (Wolf & Ripple, 2016). This lack of knowledge is a concern given that forest ungulates are heavily impacted by illegal hunting and bush-meat consumption and the conversion and degradation of lowland forests (Di Marco *et al.*, 2014). For example, while no South East Asian carnivores are assessed as Critically Endangered on the IUCN Red List of Threatened Species, eight South East Asian ungulates species are Critically Endangered (IUCN, 2017). Mouse-deer or chevrotains form a family (Tragulidae) of primitive ungulates with nine species occurring in the forests of South and South East Asia and one in Central and West Africa. Six species are listed on the IUCN Red List as Least Concern, three poorly known South East Asian species (*Tragulus versicolor*, *T. javanicus* and *T. williamsoni*) are Data Deficient and the Balabac chevrotain *Tragulus nigricans* from the Philippines is globally Endangered (IUCN, 2017). Lesser oriental chevrotain *Tragulus kanchil*, the smallest ungulate in the world, is the most widespread chevrotain species in South East Asia occurring widely across the Greater Sunda region and in continental South East Asia north to at least 18°10′N (Timmins & Duckworth, 2015). The species is the only chevrotain likely to occur in the Cardamom Forest Landscape, south-west Cambodia. The Cardamom Forest Landscape is a reef to ridge landscape covering >17 000 km^2 of largely evergreen rainforest, and has been the focus of conservation efforts by the Royal Government of Cambodia, and partner international conservation NGOs, since the early 2000s (Gray *et al.*, 2016, 2017a).

Camera-traps are widely used in South East Asia for conservation and research particularly for inventorying ground-dwelling large mammal diversity within conservation landscapes (Phan, Prum & Gray, 2010; Moo, Froese & Gray, 2017) and estimating species density and abundance for conservation impact monitoring (Rayan & Mohamad, 2009; Gray, 2012; Gray & Prum, 2012). However, robustly estimating species abundance from camera-trap data is extremely difficult unless animals have unique individual markings such as tiger *Panthera tigris* or leopard *P. pardus* (Karanth & Nichols, 1998). Given the perilous conservation status of many terrestrial mammals in the tropics, and the unreliability of index-based 'abundance' estimates for conservation monitoring (Sollmann *et al.*, 2013), new tools for monitoring unmarked animals from camera-trap data are required. To address this issue Rowcliffe *et al.* (2008) developed a random encounter model (REM) which describes the rate of contact between moving animals and static camera-traps in order to model animal density.

However, camera-traps need to be randomly placed with respect to animal movement, that is, not located in places which animals preferentially use. Thus, ruling out application of the REM to many widely used camera-trap placement strategies which, logically, try to increase the number of detections of species through targeted trap deployment (e.g. at waterholes, or on animal trails: Gray, 2012; Moo *et al.*, 2017). In this paper, I use camera-trap records from a randomly generated camera-trap grid located within one protected area, Southern Cardamom National Park, to estimate the density of lesser oriental chevrotain using the REM method of Rowcliffe *et al.* (2008). This represents an interesting use of this novel methodology to provide the first estimate of chevrotain density from anywhere in mainland South East Asia.

Materials and methods

Study area

The study was conducted within 200 km^2 of the Core Zone of Southern Cardamom National Park, Koh Kong province, Cambodia (~11°47′N 103°20′E). The study area largely comprised low-to-mid elevation evergreen forest on sandstone which was selectively logged prior to the 2002 moratorium on commercial logging in Cambodia. This forest type is dominated by Dipterocarpaceae, particularly *Hopea pierrei*. The elevation of the study area ranged between 100 and 600 m above sea level (a.s.l). As with much of the Cardamom Rainforest Landscape, the study area experiences a highly seasonal monsoonal climate with rainfall (>4000 mm per year) peaking between May and November. As a result of past hunting, the largest carnivores, tiger *P. tigris* and leopard *P. pardus*, have been extirpated from the landscape, but smaller carnivores including dhole *Cuon alpnius*, mainland clouded leopard *Neofelis nebulosa*, and sun bear *Helarctos malayanus* remain widespread (Gray *et al.*, 2017a).

Camera-trapping

A 2 × 2-km grid was superimposed over the study area and single cameras were placed as close as possible to each intersection between the horizontal and vertical lines which comprised the grid (Fig. 1). In two of the predetermined locations, cameras were not set as they were lost during transport over a river. In practice, topography and access (largely extensive cliffs) meant cameras were set between 1 m and ~200 m ($\bar{X}$ 40 m) from the predetermined locations, meaning final locations were pseudo-random. Given this pseudo-random camera-trap placement, we cannot guarantee that trap locations were completely random with respect to chevrotain movements. This aspect of camera-trap placement for REM was addressed by Rowcliffe *et al.* (2013) who suggested that provided animals are neither attracted nor repelled to camera-traps, and that cameras are not disproportionately set in areas of high animal traffic, the assumptions of REM trap spacing will largely be met. A total of 72 camera-traps (Bushnell Trophy Camera Model 119537) were operational between December 2015 and June 2016 and were set to detect animals throughout the 24-hour period taking three photographs, followed by *c.* 10 seconds of video, for each trigger. Time between successive triggers was set to 10 seconds. No cameras were baited and all photos and videos were stamped with the date and time. Cameras were set between 30 and 50 cm above, and perpendicular to the ground. All photographs were checked manually and encounters with mammals identified to species by the author. All chevrotain detections were assumed to be lesser oriental chevrotain given there is no reason to believe any other chevrotain occurs in the landscape. Data were managed using camtrapR software (Niedballa *et al.*, 2016).

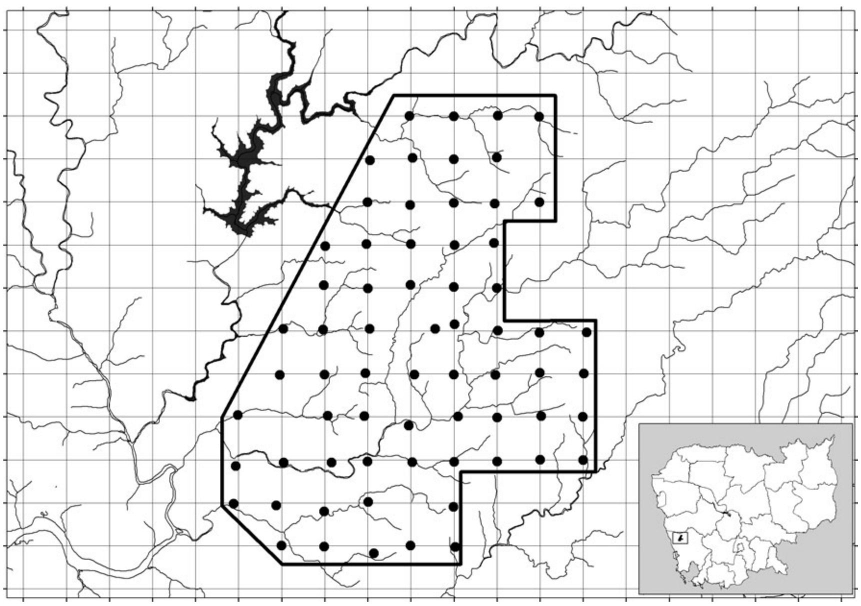

Figure 1 Location of camera-traps within camera-trap grid in the Southern Cardamom National Park, south-west Cambodia. Grid-cells are 2 × 2 km.

Density estimation

The REM was used to estimate lesser oriental chevrotain density (D) from camera-trap encounter rates:

$$D = \frac{y}{t}\frac{\pi}{vr(2+\theta)} \quad (1)$$

where y is the total number of photographic events, t camera-trap survey effort, v average speed of animal movement and r and θ the radius and angle of the camera-trap detection zone, respectively.

I defined every photographic encounter of lesser oriental chevrotain separated by >3 minutes as an individual photographic event (y) and total camera survey effort (t) as the sum of 24-hour periods each camera was operational for. Average speed of chevrotain movement (v) was obtained from Matsubayashi, Bosi & Kohshima (2003) who radio-collared five lesser oriental chevrotain in Kabili-Sepilok Forest Reserve, Sabah, Malaysia. Mean daily distance traveled for males was estimated at 519 ± 89 m and for females 574 ± 220 m. To conservatively estimate density, a figure of 600 m was used (0.6 km).

Following Balestrieri *et al.* (2016), the detection radius (r) was obtained through measuring the detection distance from a random subset (n = 20) of lesser oriental chevrotain camera-trap detections from the same camera-traps deployed in a separate study elsewhere in the Cardamom Forest Landscape. These cameras were set by the same field teams. Distance was measured through referring to the images in the field and measuring distance to distinctive features in each photograph (e.g. dead logs). r was calculated as the mean first detection distance across this dataset after testing for, and finding, normality. Following Cusack *et al.* (2015a), I calculated the angle of the camera-trap detection zone through approaching five of the cameras at perpendicular distances from both sides of the camera at 0.5 meter intervals between 0.5 and 3.0 meters and recording location, and bearing to the camera, at first trigger. As above these cameras were set within the Cardamom Forest Landscape, by the same field teams as undertook this study, but in different locations. I estimated variance in mouse-deer encounter rate ($y \cdot t^{-1}$) through non-parametric boot-strapped resampling of camera-trap locations without replacement and taking the variance of 10 000 resampled estimates. I did not account for variance in independently estimated parameters (v, r and θ). Chevrotain activity patterns were plotted automatically from the data using the *activityDensity* function in camtrapR software. This creates a density plot of records based on time recorded (Niedballa *et al.*, 2016). Spatial patterns in the encounter rate (i.e. total number of photographic events) of lesser oriental chevrotain between camera-trap stations was investigated through producing kernel density raster maps using *sp* and *spatstat* packages in R software (R Foundation for Statistical Computing, Vienna, Austria).

Results

Data were obtained from 65 camera-trap stations (two cameras were stolen and five did not produce usable photographs or failed after less than 20 camera-trap nights) for a total of 8236 camera-trap nights (t). Lesser oriental chevrotain were detected from 45 cameras (naïve trap occupancy 69%) for a total of 501 photographic events (y). There were between zero (21 camera-trap stations) and 50 photographic events per camera-trap station ($\bar{X}$ 7.7 ± SD 10.4 events per station). Based on the density surface modeling, lesser oriental chevrotain were not evenly distributed across the camera-trap grid with higher encounter rates in the slightly hillier forest of the northern and central part of the study area (Supporting information Figure S1). While chevrotain appeared to avoid some of the rarer 'habitat' types (estimated from camera-trap images) in the study area (such as grassland and areas of rock and cliffs) neither elevation, nor distance to road or village (calculated from GIS datasets), significantly influenced the number of chevrotain photographic events per camera-trap station (Supporting information Table S1; Supporting information Figure S2).

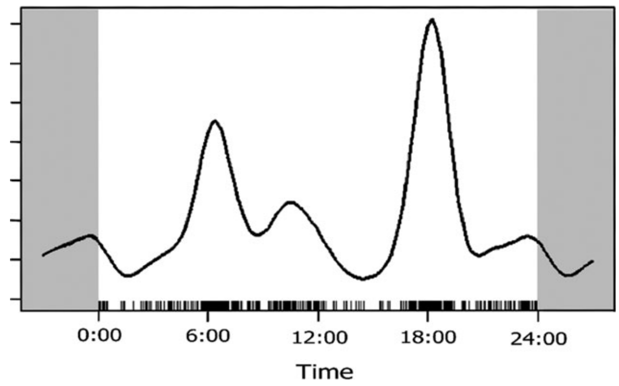

Figure 2 Activity pattern of lesser oriental chevrotain *Tragulus kanchil* from camera-trap encounters (n = 501) from the Southern Cardamom National Park, south-west Cambodia.

Four other ungulate species were detected: wild pig *Sus scrofa* (260 photographic events), northern red muntjac *Muntiacus vaginalis* (161 photographic events), Chinese serow *Capricornis milneedwardsii* (69 photographic events) and sambar *Rusa unicolor* (39 photographic events). Mean detection distance of lesser oriental chevrotain (r) from 20 encounters was 1.4 m (0.0014 km) ± 0.26 m from camera-traps. Camera-trap detection zone was estimated at 47° (equivalent to 0.82 radians). Lesser oriental chevrotain density (D) was estimated at 80.7 km^{-2} with boot-strapped 95% confidence intervals of 56.6–98.1 km^{-2}.

Although individuals were detected throughout the 24-hour cycle, lesser oriental chevrotain activity peaked around dawn (22% of photographic events between 05:00 and 07:59 hours) and dusk (31% of photographic events between 17:00 and 18:59 hours; Fig. 2). The majority of chevrotain encounters were of single individuals (93%) but there were 33 photographic events with two individuals present.

Discussion

Monitoring tropical forest ungulates is difficult (Steinmetz *et al.*, 2010) and despite their ecological and conservation significance there are few published estimates of ungulate density from tropical Asia away from the open savannah forests of South Asian tiger reserves (e.g. Jathanna, Karanth & Johnsingh, 2003; Harihar, Pandav & Goyal, 2008). In this paper, I present the first use of the REM from camera-trap data to estimate densities of forest ungulates in mainland tropical Asia. The approach has previously been successfully applied to estimate densities of the threatened endemic ungulates on Bawean Island, Indonesia (Rademaker *et al.*, 2016; Rahman, Gonzalez & Aulagnier, 2016).

The REM model contains a number of significant assumptions including that animals behave like ideal gas particles moving randomly and independently of one another and of camera-traps (Rowcliffe *et al.*, 2008). Field-based comparisons of estimates from the REM with more widely used approaches for estimating density, such as capture mark recapture and distance-based line transects, have generated both similar and diverging estimates (Rovero & Marshall, 2009; Zero *et al.*, 2013; Anile *et al.*, 2014; Cusack *et al.*, 2015a; Balestrieri *et al.*, 2016; Caravaggi *et al.*, 2016). While it is possible to obtain some data on movement parameters from camera-traps (Rahman *et al.*, 2016; Rowcliffe *et al.*, 2016) estimating movement parameters for REM is one of the approaches most difficult and controversial aspects. I obtained lesser oriental chevrotain movement data from a radio-telemetry study conducted elsewhere in the species' range (Matsubayashi *et al.*, 2003); and this may not truly reflect movement patterns in the Cardamom Forest Landscape. While data from radio-telemetry has been widely used in REM studies (Anile *et al.*, 2014; Balestrieri *et al.*, 2016; Caravaggi *et al.*, 2016; Soofi *et al.*, 2017) it is possible that the limited precision of such data may underestimate total daily movements and thus inflate density estimates.

I also modeled the entire population as if comprising the wider ranging females. Given that the social system of lesser oriental chevrotain is facultative monogamy/polygyny (Matsubayashi, Bosi & Kohshima, 2006) it is reasonable to assume a male:female sex ratio of ~1:2. Analyzing the data using sex-specific movement rates from Matsubayashi *et al.* (2003), and using 1:2 sex ratio, does not change overall density estimates significantly ($\bar{X}$ 86 individuals per km^2; Supporting information Table S2). I also did not account for variation in camera-trap detection parameters (r and θ). Camera-trap detection angle was estimated using humans rather than the, significantly smaller chevrotain. As such the detection angle may be smaller than I estimated. This would cause chevrotain density to increase – halving the detection angle within this dataset increases the density estimate by *c*. 20%. Recent approaches to more effectively model camera-trap detection areas (Hofmeester, Rowcliffe & Jansen, 2017; Howe *et al.*, 2017) may provide more precise and defensible estimates of species specific camera-trap radius and angle of detection. The occasional grouping of chevrotain (7% of capture events involved pairs) may also result in slightly conservative estimates of overall animal density and the results are best interpreted as density of chevrotain groups rather than individuals. While, given the essentially solitary nature of the species, this does not significantly impact my results Rowcliffe *et al.* (2008) recommended multiplying this group density by unbiased estimations of average group size to estimate individual density. This will be necessary for many group-living forest ungulates such as wild pig.

The results represent the first population density estimate for any chevrotain species from mainland South East Asia. Estimates of between 57 and 98 individuals per km^2 suggests that lesser oriental chevrotain remain abundant in the previously selectively logged and hunted Cardamom Forest Landscape. Heydon & Bulloh (1997) estimated densities of both lesser oriental chevrotain and greater oriental chevrotain *Tragulus napu* using distance-based line transect sampling in Ulu Segama Forest Reserve, Sabah. Densities in unlogged primary forest were 72 individuals per km^2 for greater oriental chevrotain and 39 individuals per km^2 for lesser oriental chevrotain. Given the small home range of lesser oriental chevrotain (<5.0 ha; Matsubayashi *et al.*, 2003), combined with evidence of overlap between males and females (Matsubayashi *et al.*, 2006), chevrotain densities greater than 50 individuals per km^2 seem ecologically reasonable. Throughout most of South East Asia, chevrotain species occur sympatrically. Lesser oriental chevrotain co-occurs with greater oriental chevrotain widely in the Greater Sunda region and with silver-backed chevrotain *T. versicolor* in at least some areas of Central Vietnam (Kuznetzov & Borissenko, 2004). In Malaysia Matsubayashi & Sukor (2005) suggested that, where overlapping with greater oriental chevrotain, lesser oriental chevrotain has a narrower niche. In the Cardamom Forest Landscape, only lesser oriental chevrotain is likely to occur, thus the species may occupy a wider niche, and potentially occur at higher densities, in comparison with elsewhere in the range.

Despite deploying camera-traps randomly and not targeting areas more likely to detect species of interest (c.f. many camera-trap studies in Asia, e.g. Gray & Prum, 2012; Moo *et al.*, 2017) more than 25 mammal and 20 bird species were photographed during this study including the majority of IUCN Threatened ground-dwelling large mammal species likely to be present in the landscape (e.g. dhole, clouded leopard, sambar, sun and Asiatic black bear *Ursus thibetanus*, greater hog badger *Arctonyx collaris;* site D in Gray *et al.*, 2017a). This further demonstrates that random deployment of camera-traps may have minimal impact on the ability of surveys to effectively inventory ground-dwelling large mammals in tropical forests (Cusack *et al.*, 2015b). Indeed such deployment may increase the detectability of certain species in comparison with 'traditional' mammal camera-trapping which targets obvious features such as trails and waterholes. Wearn *et al.* (2013) found that strictly random distribution of camera-traps detected four of the five Bornean cat species and suggested that the relative abundance of bay cat *Pardofelis badia*, in particular, may have previously been underestimated due to the use of non-random survey locations. In this study, the Critically Endangered Sunda pangolin *Manis javanica* was detected from 11 camera-trap stations despite being previously unrecorded from more than 22 000 camera-trap nights in non-random survey locations across the Cardamom Forest Landscape (Gray *et al.*, 2017a).

The seemingly high densities of lesser oriental chevrotain in the study area support the assertion of Timmins & Duckworth

(2015) that the species is likely fairly resilient to hunting particularly in extensive forested landscapes such as the Cardamoms. More than 100 000 snares were removed from Southern Cardamom National Park between 2010 and 2015 (Gray *et al.*, 2017b) and, as with large areas of mainland South East Asia, numbers of protected area rangers are low (~1 per 100 km^2). Chevrotain was recorded from the majority of our camera-traps (69%) and other camera-trapping across the Cardamom Forest Landscape shows similarly widespread presence throughout the landscape's evergreen forests (Gray *et al.*, 2017a). The records also largely confirm the presumed activity patterns (Matsubayashi *et al.*, 2003) and solitary nature (Timmins & Duckworth, 2015) of lesser oriental chevrotain. Lesser oriental chevrotain is regarded as a specialist of lowland forests (Timmins & Duckworth, 2015). The highest elevation records are unclear but it is believed to be restricted to below 600 m a.s.l. in the Greater Sundas and there are few confirmed records above this altitude in mainland South East Asia (Timmins & Duckworth, 2015). Lesser oriental chevrotain were recorded from five of the nine stations above 500 m a.s.l. in the study site including from the highest station located at ~ 620 m a.s.l. A compilation of camera-trap records from across the Cardamom Forest Landscape documented multiple lesser oriental chevrotain records from study grids including those with considerable camera-trapping effort above 600 m a.s.l. (Gray *et al.*, 2017a). These include records from at least three camera-trap stations >850 m a.s.l. on Phnom Dalai, Phnom Samkos Wildlife Sanctuary including one at 1020 m a.s.l. This may be higher than the highest previously confirmed altitudinal record for the species.

Conclusions

This study analyzes camera-trap data using the REM to estimate the density of a poorly known tropical forest ungulate. While there are no independent estimates of lesser oriental chevrotain densities in the study site, and obtaining these from line transects or fecal DNA analysis is likely not practical in the dense evergreen forests of the Cardamom Forest Landscape, my density estimates appear biologically reasonable and support the assertion that chevrotain are fairly resilient to the pervasive hunting typical throughout South East Asian forests. The random deployment of camera-traps, an assumption of the REM, does not appear to prevent collecting data on a wide variety of other species present in the landscape. As such I recommend further exploring the utility of this methodology, and its inherent assumptions, by conservationists in the forested tropics.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Kernel density map of lesser oriental chevrotain photographic rate (total number of photographic events per camera-trap station) across a camera-trap grid in Southern Cardamom National Park, Cambodia.

Figure S2. Relationship between the number of lesser oriental chevrotain photographic events per camera-trap station and a) distance to nearest motorbike trail; b) camera-trap elevation; and c) distance to nearest river.

Table S1. Camera-trap specific encounter rates of lesser oriental chevrotain from the Cardamom Rainforest Landscape, Cambodia and characteristics (elevation, forest type, and straight line distance to nearest river and motorable track) of camera-trap station locations.

Table S2. Sex-specific density estimates of lesser oriental chevrotain from Southern Cardamom National Park using male and female daily movement data from Matsubayashi *et al.* (2003) and assuming 1:2 male:female sex ratio.