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Population density, habitat use and activity patterns of endangered hog deer in Cambodia

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Photo on front cover: Hog deer was photographed in Camera trap. © MoE / WWF-Cambodia
Photo on Back cover: Aerial photo of Mekong Flooded Forest in Cambodia. © Adam Oswell / WWF-Cmabodia

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ORIGINAL PAPER

Population density, habitat use and activity patterns of endangered hog deer in Cambodia

Tim van Berkel[1] · Willem-Jan Emsens[1,2] · Sam Un Eam[3] · Sandra Simoes[1] · Sam Puls[1] · Naroeun Rin[3] · Lor Kimsan[3] · Merlijn Jocqué[1,4]

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Abstract
Hog deer (*Axis porcinus*) were once widespread throughout much of lowland Southern Asia, but numbers rapidly declined during the last two decades. In Cambodia, the species was considered extinct until 2006 when a small number of individuals (presumedly spp. *annamiticus*) was rediscovered along the western bank of the Mekong River, near Kratie. Since reliable data on this population are lacking, we conducted two camera trap surveys to investigate hog deer habitat use, activity patterns and density. In the first survey, camera traps were placed in a random regular grid covering all main habitat types in the region, enabling us to verify hog deer presence/absence and identify habitat use. We found that hog deer were confined to a remnant patch of tall moist grassland of approximately 2 km^2, at least in the dry season. The follow-up survey was conducted exclusively in this tall grassland patch, in which we estimated hog deer activity patterns and density using kernel density estimation and a simplified version of the random encounter model (REM). Cameras were active for a total of 1770 camera trap days, during which 609 independent hog deer encounters were recorded. Density was estimated to be 41.8 (CI: 37.93–45.72) individuals km^{-2}, equating to an estimated abundance of 84 individuals. Hog deer activity was mainly crepuscular and nocturnal. We conclude that the recently rediscovered hog deer population in Kratie province is extremely vulnerable to extinction due to its small size and its complete dependency on a tiny remnant patch of core habitat. Conservation and restoration actions to preserve and restore prime habitat are urgently required to prevent local extinction.

Keywords Camera trapping · Mammal conservation · Mekong · Random encounter model · Ungulates · Prek Prasab Wildlife Sanctuary

Introduction

Hog deer (*Axis porcinus*) were once widespread in temporal floodplains and wet grasslands near rivers throughout most of lowland Southeast Asia (Biswas and Mathur 2000; Odden et al. 2005; Maxwell et al. 2006), mainly feeding on grasses (Francis and Barrett 2008). During the last two decades, numbers collapsed due to poaching, habitat loss and wildlife trade (Brook et al. 2015; Timmins et al. 2015), resulting in the species being categorized as Endangered by the IUCN (Timmins et al. 2015). Hog deer's widespread disappearance has further ecological consequences as it is an important prey species for tiger (*Panthera tigris*) (Støen and Wegge 1996).

In Cambodia, hog deer was considered extinct until 2006, when a population was rediscovered along the western bank of the Mekong River in Kratie Province (Maxwell et al. 2006). This population is now mainland Asia's easternmost extant population (Maxwell et al. 2006), with the area of occurrence officially designated as Protected Wildlife Sanctuary in 2018 (Prek Prasab Wildlife Sanctuary). Despite its rediscovery, reliable population data remain lacking.

Ungulate densities are traditionally estimated through direct observation and distance sampling techniques, but hog

✉ Tim van Berkel
info@binco.eu

1 Biodiversity Inventory for Nature Conservation, Walmersumstraat 44, 3380 Glabbeek, Belgium

2 Ecosystem Management Research Group, Department of Biology, University of Antwerp, Universiteitsplein 1C, 2610 Wilrijk, Belgium

3 WWF Cambodia, P.O. Box 2467, #21 St. 322. Boeung Keng Kang I, Boeung Keng Kang, Phnom Penh, Cambodia

4 Aquatic and Terrestrial Ecology (ATECO), Royal Belgian Institute of Natural Sciences (RBINS), Brussels, Belgium

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deer are secretive and elusive, and may switch to nocturnal activity in human-dominated landscapes or during high daytime temperatures. Also, their detectability and visibility in dense tall grasslands are generally low, implying that traditional survey methods become ineffective. Although camera trapping is an effective method to survey elusive species (Tobler et al. 2008), density studies have traditionally been restricted to capture-recapture methodology, which only works if individual animals bear distinct markings. To estimate densities of unmarked species, such as hog deer, Rowcliffe et al. (2008) developed the random encounter model (REM). REM is based on encounter rates between animals and randomly positioned cameras and is corrected for average animal movement speed and group size. Here, we used a modified version of REM, as developed by Hofmeester et al. (2017), to estimate hog deer density. The aim of our study was to determine distribution, habitat use, density and activity patterns of the hog deer population near Kratie. Knowledge of these parameters is essential for the implementation of effective conservation measures.

Material and methods

Study area

The study area is situated near the Mekong River in Kratie Province, approximately 8 km north of Kratie (Fig. 1), in the Prek Prasab (also Prek Prasob) Protected Wildlife Sanctuary (PPWS). The area forms a complex of remnant, seasonally flooded, grasslands (dominated by *Sclerostachya fusca*, as well as *Imperata cylindrica*, *Sorghum propinquum* and other grasses (Maxwell et al. 2006)), arable fields, rice paddies, human settlements and patches of heavily degraded forest and open woodland. PPWS is under high pressure from land conversion, illegal logging and deliberate burning. Average annual temperature and rainfall equal 27.5 °C and 1707 mm respectively. The wet season generally occurs from (somewhere in) May or early June through September, but the onset can vary slightly between years. Habitat was classified using the IUCN Remote Ecosystem Monitoring Assessment Pipeline (REMAP) app (Murray et al. 2018). Three main habitat classes were distinguished in the survey area: moist tall grassland, arable land (including (bare soil) rice paddies and human settlements) and degraded open forest and woodland. Habitat was classified using a minimum of 78 ground-truthed training points per habitat class. The total

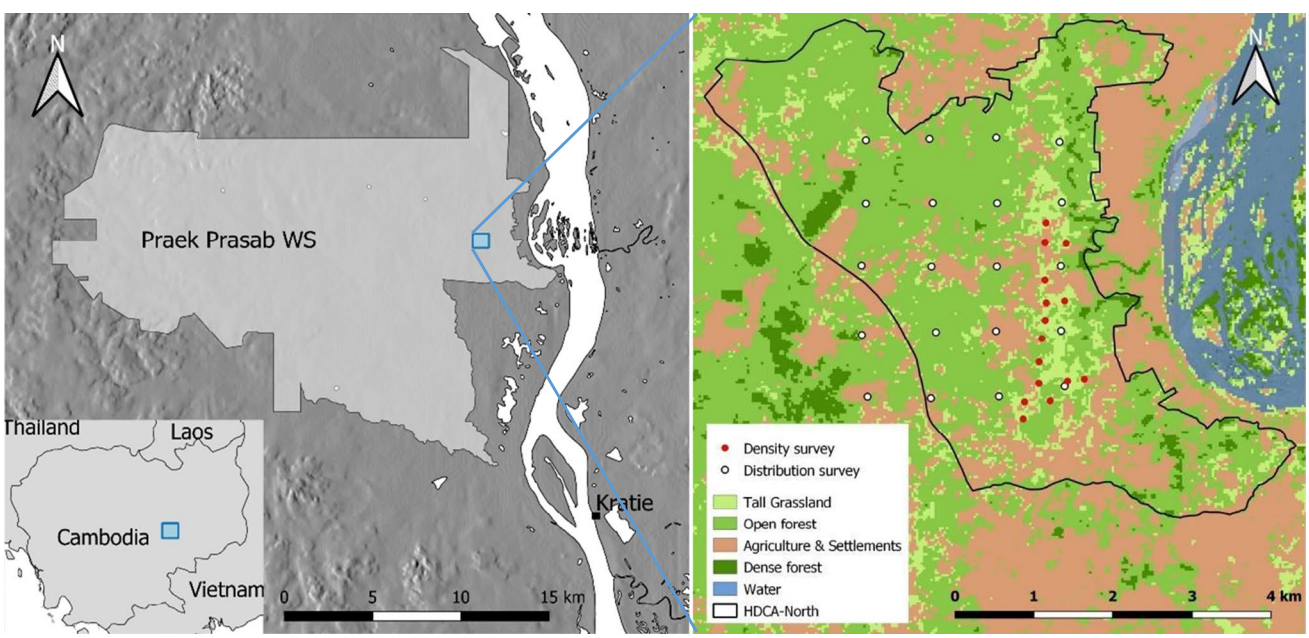

Fig. 1 Location of the survey area in the newly formed Prek Prasab Wildlife Sanctuary in Kratie Province (left). Overview of the survey area with camera stations of the distribution survey (white dots) and the density survey (red dots), with the perimeter of the northern designated hog deer conservation area (HDCA-North) (Right). Hog deer were exclusively recorded at the camera stations within the moist tall grassland habitat, not in any of the other habitat types. Open and dense forest are both degraded forest. The REMAP application was used to classify the habitats (Murray et al. 2018)

cover of the tall grassland habitat was estimated by summing up the corresponding pixels (30 × 30 m each).

Hog deer distribution and habitat use

Hog deer presence, distribution across the landscape and habitat use were first evaluated in an exploratory study during the dry season of 2018 (henceforth the 'distribution study'). Twenty motion-triggered cameras (Bushnell Trophy Cam models 119,436, 119,456 and 119875C, Bushnell, Kansas City, USA) were deployed between April and May 2018 in a predefined grid with 850-m interspacing in the area in which hog deer was rediscovered in 2006 (Fig. 1), on the west bank of the Mekong River near Kratie town (Maxwell et al. 2006). We covered the three main land use types in the region: five cameras were placed in remnant patches of moist tall grassland, five in rice paddies (= dry, arable and unvegetated soil at the time of sampling) and open arable land and ten in degraded open forest and woodland. At each predefined point, we chose the nearest location (< 50 m) with at least 6-m open view, and we attached cameras to tree trunks at a height of c. 50 cm. Camera traps were active day and night, with a 1-s delay between triggers. The Bushnell cameras were set to trigger 3 photos per trigger. Cameras were active for a consecutive period of 18 to 21 days, resulting in a total survey effort of 328 camera trap days. The survey took place during the second half of the dry season (after the annual burning of the grassland) and was concluded at the onset of the wet season, which made the area inaccessible and caused fast-growing grasses to obscure the cameras' field of view.

Hog deer density and abundance

The follow-up study (henceforth the 'density survey') was conducted in the dry season of 2020, from January (after most of the grasslands had been burned) to early June (the onset of the wet season), resulting in a total of 1770 camera trap nights. Since the exploratory distribution study revealed that hog deer are solely confined to a relatively homogeneous patch of tall grassland habitat during the dry season, we placed a total of 15 cameras (nine Bushnell Trophy Cam HD Essential E3, model 119,837 and six Cuddeback F2 IR Plus, model 1309) in this core zone. Cameras were deployed in a randomly placed grid with 500-m interspacing allowing cameras to be spread out throughout the study area (Fig. 1).

Five bamboo stick markers were placed in a straight line in front of each camera at fixed distance intervals (2.5, 5, 7.5, 10, 12.5 m; sensu Hofmeester et al. (2017)) so that each marker was visible on camera trap photos (Plate 1). Camera traps were programmed to take three photos per trigger, day and night, with a 1-s delay between triggers. An independent event constituted of an animal entering and leaving the camera's field of view (Palencia et al 2021).

Plate 1 A male hog deer recorded at a camera trap in the study area. The bamboo sticks with 2.5 m interspacing are clearly visible

Table 1 Parameters used in the REM formula for hog deer density estimation

Parameter	Units
Independent photographic encounters with midline crossing (N)	389
Survey effort (24 h-trap days)	1770
Estimated average daily movement (km 24 h^{-1})	1.671
Effective detection distance (EDD) (km)	0.00720
Average group size	1.24

Data were analysed in R 4.1.2 (R Core Team 2021); photos were processed using the CamtrapR package (Niedballa et al. 2016). Francis and Barrett (2008) was followed for species identification.

Hog deer density was calculated using a modified version of the Random Encounter Model (REM), which allows for density estimation based on animal encounter rates without the need for individual recognition (Rowcliffe et al. 2008), sensu Hofmeester et al. (2017). The modified REM version differs from the original model in that only independent animal encounters in which the animal passes through the midline of the camera's field of view are included, so that detection angle θ can be set to 0. The model requires estimates of the following input parameters: number of independent hog deer encounters (y), total camera survey effort (t, in days), average daily hog deer travel distance (v, in km day^{-1}), and the radius (r, in km) and angle (θ) of the camera trap detection zone (Table 1). Average group size was calculated by averaging group size from all independent events where hog deer crossed the field of view midline. Daily travel distance

estimates for hog deer are lacking in published literature, so we used the model developed by Carbone et al. (2004) which estimates travel distance of mammal species based on mean species body mass, taxonomic group, diet type and foraging habitat. Average body mass was calculated by averaging the weighted body mass of all detected females (we assume 30 kg), males (we assume 50 kg) and juveniles (we assume 15 kg). Following Hofmeester et al. (2017), the radius was taken to be the effective detection distance (EDD), calculated from distance classes using a half-normal function for independent encounters (estimated with the mrds package (Laake et al. 2015)). Means (±95% bootstrap confidence intervals) of EDDs and resulting density estimations were calculated by bootstrapping.

Hog deer abundance was calculated by multiplying density by the total area of continuous grassland as classified using the REMAP app (see above).

Activity patterns

Hog deer activity patterns were calculated using kernel density estimation with the overlap package, in which relative activity levels are plotted against time of the day (Meredith and Ridout 2014). Following Ridout and Linkie (2009), we only included observations with > 30 min between consecutive triggers to assure independence of observations.

Results

Distribution study

Total trap effort of the hog deer distribution survey in 2018 was 327 trap nights, during which a total of 27 independent hog deer encounters were recorded. Hog deer were exclusively recorded at the five camera stations within the moist tall grassland habitat and were never encountered in any of the other habitat types. Data from three cameras could not be retrieved: two cameras (one on arable land and one in degraded forest) were stolen and one (on arable land) malfunctioned.

Density study

Camera traps were active for a total of 1770 camera trap days in the remnant patch of moist tall grassland. A total of 609 independent hog deer encounters were recorded (with records at all 15 camera stations), and hog deer crossed the midline in 389 of these occasions. Average group size equalled 1.24 individuals with an observed male:female:juvenile ratio of 3.2:3.3:1.0.

Density was estimated to be 41.8 (95% CI = 37.9–45.7) individuals km^{-2}. Parameters used to calculate hog deer density using REM are listed in Table 1.

Using the REMAP application (Murray et al. 2018), the tall grassland patch was estimated to be approximately 2.0 km^2 in size, equating to an estimated hog deer abundance of 90 (95% CI = 76–91) individuals within this core zone.

Activity patterns

Cameras mostly recorded hog deer at dawn, dusk and at night (Fig. 2), indicating high levels of night-time activity.

Discussion

We confirmed the continued presence of a small but seemingly well-established population of hog deer in a narrow strip of moist tall grassland habitat near the Mekong River in Kratie province, as first reported by Maxwell et al. (2006), and we provided a baseline methodology for long-term monitoring of this population.

Density and abundance estimation

The estimated density of 41.8 individuals km^{-2} is on the higher side of what is reported in other studies, with density estimates of 3.1 (Ahmed and Khan 2015), 7.5 (Dinerstein 1979), 7.9 (Tamang 1982), 8.5 (Schaaf 1978), 13.2 (Odden et al. 2005), 19.1 (Dhungel and O'Gara 1991), 35 (Seidensticker 1976) and 77.3 individuals km^{-2} (Odden et al. 2005). We see several nonexclusive reasons for the high density in our study area. First, it is likely that ongoing habitat loss and human encroachment have led to a forced concentration of all remaining hog deer into the small remnant patch of suitable tall grassland habitat. In addition, the current lack of apex predators in the area might strengthen this local supersaturation. Second, high densities could be an artifact of seasonal habitat compression: our surveys were conducted during the dry season, which is when tall grassland cover is at its lowest and restricted to the wettest areas only. This may result in a seasonal rather than a structural concentration of hog deer, which may potentially be relaxed during the wet season (when tall grassland cover increases and when rice paddies are vegetated). Third, the model that we used for density estimation (i.e. a simplification of REM) relies on several assumptions and requires input parameters which can potentially introduce significant bias when estimated incorrectly. For example, *average daily travel distance* particularly affects the density estimate, and it is difficult to quantify accurately. The day range model (Carbone et al. 2004) we used here may for example underestimate

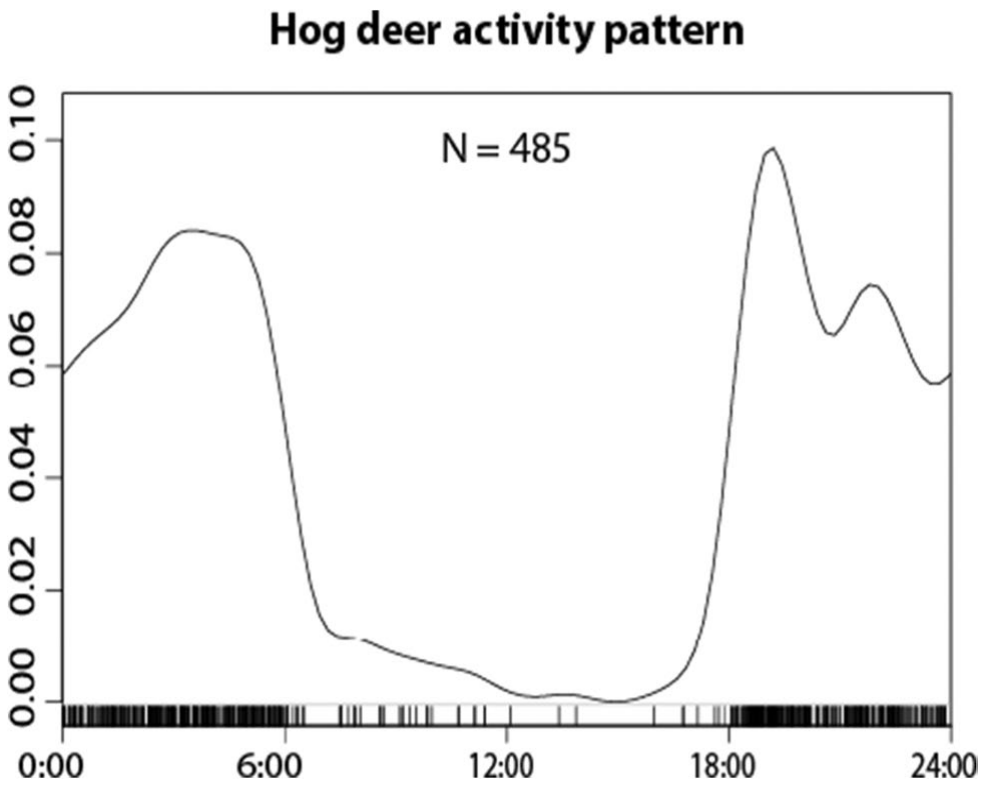

Fig. 2 Hog deer activity patterns (kernel density estimation) in the study area, derived from all stations in the moist tall-grassland habitat. The x-axis represents time of the day (24 h), and the y-axis represents relative activity levels

daily travel distances, as it is derived from telemetry with low-fix frequency (C. Carbone *pers. comm.*). An underestimation of travel distance would result in an overestimation of density (Rowcliffe et al. 2012). For instance, if the daily travel distance doubles to 3.34 km, the density estimate halves to 22.4 individuals per km^2. However, given the very small size of the remaining patch of prime habitat (2 km^2), we believe that the estimated travel distance of 1.67 km per day is more likely to be an over- rather than underestimation.

To increase accuracy of the model estimation, GPS sensors with high-fix frequency or speed estimates from camera traps are recommended (Rowcliffe et al. 2016), but this was beyond the remit of this study.

Activity patterns

Where undisturbed, hog deer are mainly crepuscular with some day-time activity (Dhungel and O'Gara 1991), whilst in areas of high human population or high hunting pressure they may shift to nocturnal activity (Timmins et al. 2015). In our study area, hog deer were almost exclusively confined to crepuscular and night-time activity, which matches our observations of high human pressure in the area (pers. obs. van Berkel et al.). Feral and domestic animals (including dogs) as well as people were abundant throughout the study area.

Conservation and restoration prospects

Our study shows that, despite widespread habitat loss and degradation, hog deer can persist in small remnant patches of core tall grassland habitat. Even so, the dependency of hog deer on the isolated and narrow (100–900 m wide, 2.0 km^2) strip of tall grassland close to the densely populated Mekong River in Kratie makes this population extremely vulnerable. Intensified slash-and-burn agriculture, poaching, attacks by domestic dogs and encroachment of rice paddies and human settlements are omnipresent (pers. obs. van Berkel et al.), and loss of the few remaining patches of tall grassland will undoubtedly lead to local hog deer extinction within decades. Since the area harbours one (and probably the largest) of the only two known populations of *A. p. annamiticus* in Cambodia (Brook et al. 2015), we believe that conservation efforts in this region need acute reinforcement. Efforts should include strict preservation of remaining prime habitat, raising local and regional awareness, restricting dog presence in the habitat and frequent patrolling to actively safeguard all conservation measures. Such measures may locally and temporarily secure the species' immediate future, but long-term survival can only be safeguarded by increasing habitat connectivity and by actively restoring the species' tall-grassland habitat (e.g. from abandoned rice paddies). We emphasize that more surveys are needed near the Mekong River to investigate hog deer presence, and these surveys should target the widely scattered patches of

moist tall grassland. Given hog deer's overall elusiveness, we believe that more sub-populations of hog deer may be rediscovered in Cambodia. In addition, future studies should also investigate potential seasonal variation in habitat use whilst exploring possibilities for restoration of the moist tall grassland habitat.

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Author contribution TVB, WJE, SP and MJ designed the research; TVB, WJE, SUE, SP, NR, LK and MJ collected the data; TVB, WJE, SS and SP analysed the data; TVB led the writing of the manuscript and all authors contributed to drafts and gave approval for publication.

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Availability of data and material Data and other material are available on request.

Code availability Code is available on request.

Declarations

Conflict of interest The authors declare no competing interests.

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