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Original article

Establishing a monitoring baseline for threatened large ungulates in eastern Cambodia

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Monitoring ungulate populations is an essential part of wildlife management with ungulates performing essential ecosystem roles including structuring populations of large carnivores. A number of ungulate species in Southeast Asia are also globally threatened and are therefore important conservation targets in their own right. We estimated large (> 15 kg) ungulate densities in two protected areas, i.e. Mondulkiri Protected Forest and Phnom Prich Wildlife Sanctuary, in eastern Cambodia using distance-based line transect sampling. During the 2009/2010 and 2010/2011 dry seasons, we surveyed 110 line transects (randomly distributed across 3,406 km^2) for a total of 1,310 km. We used DISTANCE 6.0 to model detection functions from observations of banteng *Bos javanicus*, wild pig *Sus scrofa* and red muntjac *Muntiacus muntjak* generating estimates of group density, cluster size and individual density. Estimated densities ± SE were 1.1 ± 0.2 individual banteng/km^2, 1.4 ± 0.4 individual wild pig/km^2 and 2.2 ± 0.2 individual red muntjac/km^2 giving an overall density of approximately 4.7 large ungulates/km^2. Although wild pig and red muntjac densities were within the range of estimates reported from ecologically similar protected areas in tropical Asia, overall large ungulate density is much lower than the intrinsic carrying capacity of deciduous dipterocarp forest. This appears largely to be due to the scarcity of large deer (i.e. hog deer *Axis porcinus*, sambur *Cervus unicolor* and Eld's deer *Cervus eldii*) as a result of extensive historic hunting. Current large ungulate densities appear too low to support a viable tiger *Panthera tigris* population in the long term, and ungulate recovery, driven by strong protected area management, needs to be achieved before tiger populations can be restored.

Please note that the supplementary information, including Appendix SI mentioned in this article, is available in the online version of this article, which can be viewed at www.wildlifebiology.com.

Key words: deciduous dipterocarp forest, distance sampling, Indochina, tiger prey species, wild cattle

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Mainland Southeast Asia forms part of the Indo-Burma biodiversity hotspot and is thus a top priority for conservation and wildlife management (Myers et al. 2000). However, Southeast Asian biodiversity is chronically threatened due to the most rapid global rate of forest conversion and intense pressures on natural resources from high human population densities and a huge market for medicinal wildlife products (Sodhi et al. 2004, 2009, Nijman 2010). Subsequently, the region supports the highest global concentration of threatened terrestrial mammals (Schipper et al. 2008) and active conservation management is necessary for stemming regional biodiversity losses (Koh & Sodhi 2010). A critical requirement of all

conservation projects is to have measures of effectiveness concerning the achievement of conservation goals. The importance of evidence-based conservation, with the success or failure of conservation interventions supported by robust monitoring data, is now widely accepted within the conservation community (Sutherland et al. 2004, Pullin & Knight 2009). However, in Southeast Asia, few examples exist of robust monitoring systems for assessing the health of populations of focal species and the impact of conservation activities upon them (but see O'Kelly & Nut 2010, Ryan et al. 2011).

Monitoring large (> 15 kg) ungulate populations is an essential part of wildlife management with ungulates performing key ecosystem roles including structuring populations of large carnivores, dispersing seeds and influencing vegetation patterns (Adler et al. 2001, Karanth et al. 2004, Prasad et al. 2006). With the global focus on tiger *Panthera tigris* conservation and recovery (Seidensticker 2010), monitoring large ungulates in Asia is essential given that prey densities appear to be a key determinant of tiger population dynamics (Karanth et al. 2004). A number of regionally endemic, or near-endemic, large ungulates that exist in Southeast Asia are also globally threatened, and they are thus key conservation targets in their own right. These species include saola *Pseudoryx nghetinhensis*, wild water buffalo *Bubulus arnee*, banteng *Bos javanicus*, Eld's deer *Cervus eldii,* hog deer *Axis porcinus* and large-antlered muntjac *Muntiacus vuquangensis*. Despite the acknowledged importance of monitoring ungulate populations, there are no published large ungulate densities from anywhere in mainland Southeast Asia obtained using statistically robust survey methodologies.

The plains of northern and eastern Cambodia were formerly described as one of the 'great game-lands of the world; a Serengeti of Asia', and they supported a diverse and abundant megafauna of ungulates, predators and scavengers (Wharton 1957, Tordoff et al. 2005). However, Cambodia suffered considerable political instability and conflict throughout the 20th century intensifying during the Lon Nol (1970-1975) and Pol Pot (1975-1979) regimes (Chandler 2000). During this period, there is evidence of large declines in the regional population and distribution of large mammal species including tiger, leopard *P. pardus*, Asian elephant *Elephas maximus*, wild cattle and Eld's deer and hog deer (Duckworth & Hedges 1998, Loucks et al. 2008). These declines were associated with a proliferation of firearms, the development of an external market for wildlife products and, particularly during the Khmer Rouge era, government-sponsored hunting (Loucks et al. 2008). This hunting pressure possibly led to the global extinction of one large ungulate species endemic to Indochina: the kouprey *Bos sauvelli*. In this paper, we report the first robust ungulate density estimates from anywhere in mainland Southeast Asia in order to provide a monitoring baseline for two protected areas in eastern Cambodia. We also test the ecological prediction that large ungulate densities in eastern Cambodia are lower than ecologically similar protected areas in the Indian subcontinent due to intense historic hunting pressure, and we use our results to assess the potential for tiger population recovery in the landscape.

Material and methods

Study area

We estimated large ungulate densities in the core areas of two adjacent protected areas in eastern Cambodia: Mondulkiri Protected Forest (MPF; 3,500 km^2 approximately centered on 12.08°N, 106.05°E) and Phnom Prich Wildlife Sanctuary (PPWS; 2,700 km^2 approximately centered on 12.40°N, 107.00°E; Fig. 1). These lowland (approximately 100-300 m a.s.l.) protected areas are dominated by deciduous dipterocarp forest with smaller areas of mixed deciduous and semi-evergreen forest (Phan & Gray 2010). Seven species of large native ungulates are known to be present within MPF and PPWS: wild water buffalo, gaur *Bos gaurus*, banteng, sambar *Rusa unicolor*, Eld's deer, wild pig *Sus scrofa* and red muntjac *Muntiacus muntjak* (Phan et al. 2010, Gray et al. 2012). Since 2005, law enforcement efforts in both protected areas have been initiated to limit hunting pressure on these ungulate species, all of which are protected under Cambodian forestry law.The study area forms part of a level-one tiger conservation landscape (Sanderson et al. 2010) and has been identified as one of 12 critical tiger conservation and recovery landscapes by the World Wide Fund for Nature (Wikramanayake et al. 2011). Despite extremely low numbers, Lynham (2010) considered the landscape irreplaceable for Indochinese tiger *P. t. corbetti* conservation, representing the only large block of dry forest habitat in Southeast Asia with a reintroduction programme recommended.

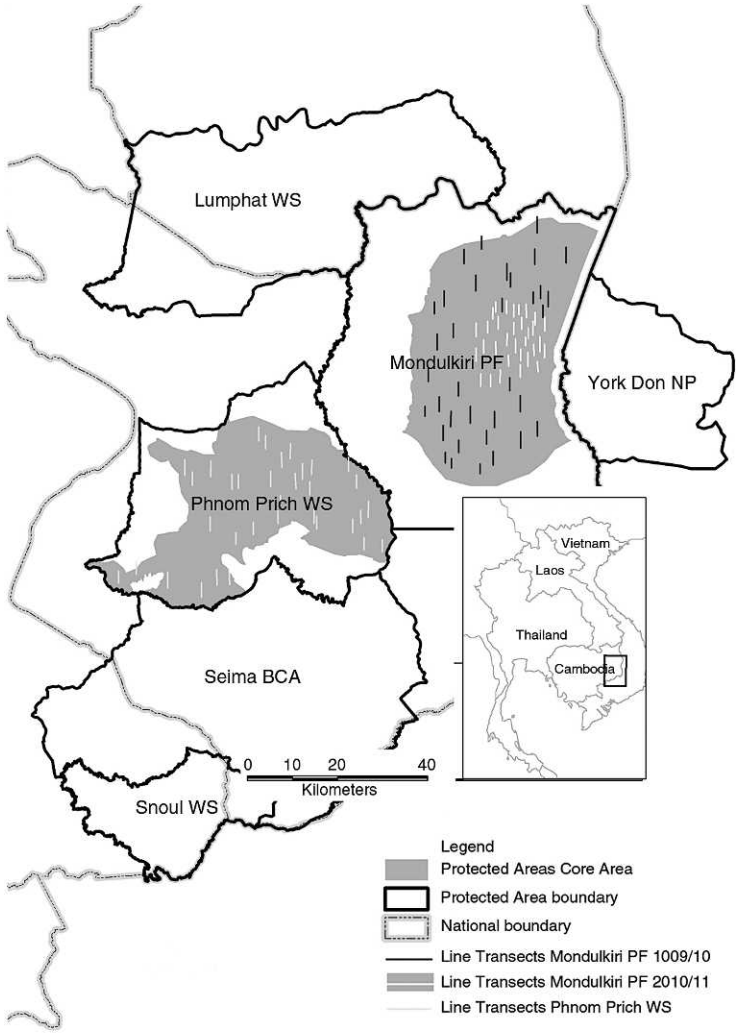

Figure 1. Location of Mondulkiri Protected Forest (MPF) and Phnom Prich Wildlife Sanctuary (PPWS), eastern Cambodia, showing the core zones of both protected areas and the locations of line transects (MPF-outer core surveyed in 2009/2010, black lines; MPF-inner core surveyed in 2010/2011, white lines; PPWS surveyed in both years, grey lines).

Line transect surveys

We estimated ungulate densities using distance-based line transect sampling. This methodology is standard for estimating ungulate tiger prey densities in protected areas in the Indian subcontinent (Karanth & Nichols 2002) and addresses two of the most problematic aspects of animal abundance estimation: spatial sampling and detectability (Williams et al. 2002, Thomas et al. 2010). We used the Survey design function in DISTANCE 6.0 (Thomas et al. 2010) to plot between 34 and 38 line transects in each of 1) the core zone of PPWS (1,670 km^2), 2) MPF outer core (1,276 km^2) and 3) MPF inner core (460 km^2). The latter roughly corresponds to an area identified and proposed by the Cambodian government to be a strictly protected tiger recovery zone. Although hunting of all ungulates is prohibited within the protected areas, illegal hunting occurs and, based on ranger-patrol data, appears higher in PPWS and MPF outer core than in MPF inner core.

Each line transect was 1-4 km long and each was surveyed between one and 10 times during the dry season of 2009/2010 (PPWS: 33 transects with a total of 155 km, and MPF outer core: 38 transects with a total of 273 km) and the dry season of 2010/2011 (PPWS: 34 transects with a total of 467 km, and MPF inner core: 38 transects with a total of 415 km). In PPWS, the same transects were surveyed in both 2009/2010 and 2010/2011 whilst in MPF, the outer core was surveyed in 2009/2010 and inner core in 2010/2011. Figure 1 indicates the locations of transects within the study area and indicates which transects were surveyed during which years.

Surveys followed the protocols of Karanth &

Nichols (2002) for line-transect sampling of ungulate tiger prey species with two observers slowly walking the line transects at dawn (start at 06:30-07:00) and dusk (finish at 17:30-18:00). All large ungulate observations were recorded with the species, number of animals (cluster size), distance between the animal or centre of a group of animals and the observers on the line (with a laser rangefinder), compass bearing to the animal or to the centre of a group of animals and compass bearing of the transect line noted.

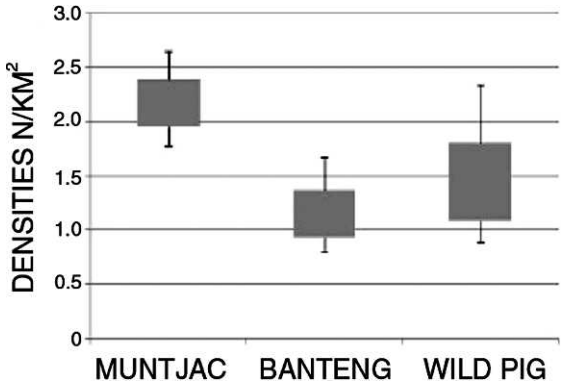

Figure 2. Density estimates (number of individuals/km^2) for red muntjac, banteng and wild pig in Mondulkiri Protected Forest and Phnom Prich Wildlife Sanctuary based on distance-based line transect sampling. Boxes indicate mean ± one Standard Error; whiskers indicate upper and lower 95% confidence intervals.

Line transect data analysis

We used the Conventional Distance Sampling (CDS) engine in software DISTANCE 6.0 (Thomas et al. 2010) to estimate species density. In order to meet the recommendation of a minimum of 40-60 observations for fitting detection functions (Buckland et al. 2001), we estimated densities only for ungulate species with > 50 observations. Prior to modelling, data were right-truncated to prevent the inclusion of additional adjustment terms which fit a long tail to the detection function but reduce precision for little gain (Thomas et al. 2010). The model which best described the detection process was selected on the basis of Akaike Information Criteria values corrected for small sample size (AIC_c). Due to the limited number of encounters of each species in each sampling stratum (i.e. PPWS, MPF outer core and MPF inner core), a single 'global' detection function was fitted to all detections of each species and this was used to calculate stratum-specific and landscape-wide densities. Using the selected model, we derived estimates of group density, cluster size and individual density for each species. We estimated expected cluster size by regressing log-cluster size against the estimated probability of detection except for banteng where checking for size bias in detection of animal clusters led to a non-significant regression equation at $\alpha = 0.10$ (Drummer & McDonald 1987); therefore, we used the mean observed cluster size (5.1 ± SE 0.6) for analysis. In order for our density estimates to be comparable with those from ecologically similar landscapes in South Asia (e.g. Karanth & Nichols 2000, Bagchi et al. 2003, Wegge & Storaas 2009), and to assess the potential carrying capacity for tiger in our study area, we present, and discuss in the text, individual (i.e. number of individuals of each species estimated/km^2) rather than group densities.

Table 1. Estimated large ungulate densities in Mondulkiri Protected Forest inner core (MPF-core), Mondulkiri Protected Forest outer core (MPF-outer), Phnom Prich Wildlife Sanctuary (PPWS) and across all three stratum (Landscape) based on distance-based line transect sampling. The table shows the number of observations included in models (N), density of groups (D_g), mean cluster size (Y), density of individuals (D_i) and population size (95% confidence interval range rounded to nearest 10) for banteng, wild pig and red muntjac.

Species	Stratum	N	D_g ± SE (km^{-2})	Y	D_i ± SE (km^{-2})	Population size
Banteng	MPF-core	31	0.4 ± 0.05		1.9 ± 0.4	600-1280
	MPF-outer	8	0.2 ± 0.05		0.8 ± 0.3	500-2200
	PPWS	12	0.1 ± 0.03		0.7 ± 0.2	600-2020
	Landscape	51	0.2 ± 0.03	5.1	1.1 ± 0.2	2700-5690
Wild pig	MPF-core	19	0.4 ± 0.07		1.9 ± 0.5	500-1470
	MPF-outer	14	0.4 ± 0.08		1.9 ± 0.6	1400-4330
	PPWS	15	0.2 ± 0.04		1.0 ± 0.3	1595-2860
	Landscape	48	0.3 ± 0.04	5	1.4 ± 0.4	890-7970
Red muntjac	MPF-core	82	2.6 ± 0.3		2.8 ± 0.3	1020-1660
	MPF-outer	43	2.3 ± 0.4		2.5 ± 0.5	2160-4590
	PPWS	57	1.4 ± 0.3		1.5 ± 0.3	1740-3710
	Landscape	182	2.0 ± 0.2	1.1	2.2 ± 0.2	6060-9030

Results

We recorded six large ungulate species, gaur (three encounters), banteng (63 encounters), Eld's deer (two encounters), sambar (three encounters), wild pig (58 encounters) and red muntjac (198 encounters) during line transect surveys. However, sufficient encounters to model detection functions, and hence estimate density, were only obtained for banteng, wild pig and red muntjac. Details of the best-fitting models and detection curves for each species are given in the online only, supplementary information (Appendix SI). Landscape-wide mean densities ± SE were 1.1 ± 0.2 individual banteng/ km^2, 2.2 ± 0.2 individual red muntjac/km^2 and 1.4 ± 0.4 individual wild pig/km^2 giving an overall density of approximately 4.7 large ungulates/km^2 (Fig. 2). For all three species, stratum-specific density estimates were higher in MPF inner core than the MPF outer core and PPWS (Table 1). This difference was more pronounced for banteng than for wild pig and red muntjac. Estimated population sizes across the entire 3,406 km^2 study area were between 2,700 and 5,700 banteng (with an estimated population of 600-1,300 in MPF inner core), 3,000-8,000 wild pig (500-1,500 in MPF inner core) and 6,000-9,000 red muntjac (1,000-1,600 in MPF inner core; see Table 1).

Discussion

Despite the importance of the region for globally threatened large ungulates (Tordoff et al. 2005) and tiger conservation (Simcharoen et al. 2007, Lynham 2010), no published estimates of ungulate densities, based on robust distance-based line transect sampling, exist for mainland Southeast Asia. We provide the first large ungulate density estimate for the region and report densities of approximately 4.7 large ungulates (banteng, wild pig and red muntjac combined)/ km^2 in the core areas of MPF and PPWS, eastern Cambodia. However, this estimate excludes the three ungulate species detected during surveys which were encountered insufficiently often to reliably model detection functions and hence estimate density (i.e. gaur, sambar and Eld's deer), and it may therefore underestimate total ungulate density in the landscape. Fitting a single detection function to all encounters of large deer and wild cattle (i.e. banteng, gaur, sambar and Eld's deer; 66 observations) gives a landscape-wide density estimate ± SE of 1.7 ± 0.4 individuals/km^2. Whilst within the 95% confidence intervals of the density estimate based solely on banteng encounters, this is 30% higher than the mean banteng density estimate. This suggests that excluding gaur, sambar and Eld's deer encounters slightly negatively biased the overall density estimates for ungulates in the landscape.

The inner core of MPF supported higher densities of all three species of ungulates for which density could be estimated than the other two survey strata. The higher ungulate densities in MPF inner core are probably due to the area's remoteness and inaccessibility, and hence reduced hunting pressure, in comparison with MPF outer core and PPWS. Our data therefore provide strong and consistent support for the importance of the inner core area of MPF for large ungulate populations and this provides strong evidence in support of the proposal of the site as Cambodia's first strictly protected tiger recovery zone.

Published total (i.e. across all species sampled) wild large ungulate densities within South Asian protected areas range between seven (Jigme Singye Wangchuck National Park, Bhutan; Wang 2010) and > 250 (Bardia National Park, Bhutan; Wegge & Storaas 2009) individuals/km^2 with > 50 individual ungulates/km^2 being the norm in most Indian tiger reserves (Karanth & Nichols 2000). Our estimates, of < 5 individual ungulates/km^2 are thus lower than any published estimates for large ungulate densities in tropical Asia. This is despite the potential for high ungulate densities in deciduous dipterocarp forest. In ecologically similar lowland deciduous Sal *Shorea robusta* forest in Ranthambore Tiger Reserve, India, ungulate density is approximately 75 animals/km^2 (Bagchi et al. 2003). This suggests that ungulate populations in MPF and PPWS remain severely depressed by hunting. The low ungulate density, in comparison with ecologically similar South Asian protected areas, seems to result from the extremely low densities of large deer species i.e. hog deer, sambar and Eld's deer. Our estimates of red muntjac density are similar to those from published studies in India: red muntjac mean density 2.1 ± SD 1.5 individuals/km^2; N = 6 sites: Wegge & Storaas (2009), Karanth & Sunquist (1992), Karanth & Nichols (2000), Jathanna et al. (2003) and Wang (2010). In contrast, large deer densities are much higher in South Asian protected areas e.g. mean sambar density 7.0 ± SD 6.3 individuals/km^2; N = 8 sites: Harihar et al. (2008), Karanth & Nichols (2000), Karanth & Sunquist (1992), Bagchi et al. (2003), Jathanna et al. (2003) and Wang (2010) and Chittal *Axis axis*

mean density 65.5 ± SD 6.3 individuals/km^2; N = 8 sites: Wegge & Storaas 2009, Harihar et al. (2008), Karanth & Nichols (2000), Karanth & Sunquist (1992), Bagchi et al. (2003) and Jathanna et al. (2003).

The limited number of encounters with larger deer in MPF and PPWS suggests that populations of these species have been severely depressed by hunting; Wharton (1957) reported an abundance of Eld's deer throughout northern and eastern Cambodia in the 1950s. Whilst the low encounter rates of sambar and Eld's deer may be due to a behavioural effect, for example species-specific responses to illegal hunting, and it is inadvisable to assume that low encounter rates on line transects equates to low density, an independent sampling method in both protected areas, i.e. camera-trapping, has also produced few encounters of large deer. In > 7,000 camera-trap nights, in both MPF and PPWS, just five photographs of sambar were obtained compared with 160 of banteng and 330 of wild pig (Phan et al. 2010). Eld's deer have only been photographed in the landscape when camera-trapping has targeted seasonal waterholes known to be used by the species. Low densities and slow recoveries of large deer, even when other ungulate species are increasing, has been noted elsewhere in Southeast Asia (Aung et al. 2001, Steinmetz et al. 2010), and it may be that these species are slower to recover from hunting-induced population declines than other ungulates. In terms of tiger recovery, low densities of large deer are worrying as deer make up > ¾ of prey consumed by tiger across most of the species' range (Karanth & Nichols 2002).

Based on our estimates of ungulate density, it is possible to extrapolate the number of tigers which MPF and PPWS could currently support. Studies across a number of tiger range countries have demonstrated a positive relationship between tiger abundance and prey density (Karanth & Sunquist 1995, Karanth et al. 2004, Smith et al. 2011). At low ungulate prey densities, the evidence suggests a linear relationship with female home-range size calibrated so as to provide a similar prey biomass, approximately 120,000 kg/home range (Smith et al. 2011). Converting our mean estimates of landscape-wide ungulate density into biomass (assuming an average individual biomasses of banteng 300 kg, wild pig 50 kg and red muntjac 20 kg; Karanth & Sunquist 1992) suggests approximately 440 kg of ungulate biomass/km^2. Using the relationship in Smith et al. (2011), and the model of Karanth et al. (2004), which applies an average kill rate of 50 ungulates/tiger/year from a base population of 500 ungulates (i.e. off-take of 10%/year), suggests a potential female tiger home-range size in our eastern Cambodia study area of approximately 260 km^2. This equates to a population of approximately 13 breeding female tigers across the 3,400 km^2 study area.

This is less than the 25 breeding female tigers (ca 75 individuals), identified as the threshold for a source site by Walston et al. (2010), and is well below the levels of prey required to support 50 breeding females (ca 150 tigers), which was suggested for long-term population viability (Walston et al. 2010). Therefore, whilst current ungulate prey levels in MPF and PPWS could support a small number of tigers, such a population would unlikely be viable in the long term. Based on estimates of intrinsic growth rates of Southeast Asian large ungulates (R_{max} 0.3-0.5; Steinmetz et al. 2010), recovery to prey densities sufficient to support 25-50 breeding female tigers would take 6-12 years. However, for such a recovery of prey species to occur, strong protected area management, to reduce ongoing threats of both habitat loss and hunting, is required. Regular monitoring of large ungulates, through distance-based line transect surveys, is also essential to ensure that ungulate populations increase to sufficient numbers to support a viable tiger population prior to any reintroductions.

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