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Status and conservation implications of a newly discovered large-antlered muntjac population in Cambodia

Pablo Sinovas[1,*], Ioannis Alexiou[1], Oliver Roberts[1], Jeremy Holden[1], Nasak Chantha[1], Andrew Tilker[2,3]

[1]Fauna & Flora, 19 Street 360, 120102 Phnom Penh, Cambodia
[2]Re:wild, PO Box 129, Austin, Texas, 78767, USA
[3]Leibniz Institute for Zoo and Wildlife Research, 10315 Berlin, Germany

ABSTRACT: The large-antlered muntjac *Muntiacus vuquangensis*, a Critically Endangered deer found only in the Annamites ecoregion (Vietnam, Laos, and northeastern Cambodia), has undergone severe population declines as a result of widespread snaring across its range. Little is known about the newly discovered large-antlered muntjac population in Cambodia, and this lack of knowledge hinders the development of targeted conservation strategies and the implementation of robust monitoring. From February 23 to July 27, 2021, we collected landscape-scale camera-trapping data on the Cambodian population in Virachey National Park. We recorded the species in 6 camera-trap stations in 2 of 7 areas surveyed. We analysed the camera-trap data with single-species Bayesian occupancy models to understand factors influencing occurrence and to produce a robust baseline for the species. Large-antlered muntjac occurrence had a positive relationship with elevation and a negative relationship with a least-cost-path measure of remoteness. Mean ± SD estimated occupancy was estimated to be 0.1 ± 0.17 across all stations, and 0.30 ± 0.29 and 0.25 ± 0.15 for the 2 grids where the species was detected. Our results provide new information on the distribution of large-antlered muntjac in Cambodia and can be used to target anti-poaching efforts and monitor population trends over time. Virachey National Park appears to be a stronghold for the species, and conservation actions are needed to ensure that its large-antlered muntjac population does not face the same fate as populations in other parts of the species range.

KEY WORDS: Southeast Asia · Camera-trap · Large-antlered muntjac · *Muntiacus vuquangensis* · Occupancy · Snaring · Cambodia

1. INTRODUCTION

Southeast Asia is a global hotspot for mammal diversity, but unfortunately the region has experienced widespread habitat loss (Wilcove et al. 2013) and high levels of unsustainable hunting (Harrison et al. 2016). As a result, many of its mammal species are now threatened with extinction (Schipper et al. 2008). Within Southeast Asia, the Annamites ecoregion — centred on the Annamites mountain range of Cambodia, Laos and Vietnam — has especially high levels of endemism and unsustainable hunting and has been identified as important for conservation actions to avert mammal extinctions (Tilker et al. 2020). For the saola *Pseudoryx nghetinhensis*, a recently discovered primitive bovid endemic to the Annamites, time is

*Corresponding author: pablo.sinovas@fauna-flora.org

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running out: it has been almost 10 yr since the species was last recorded in the wild (WWF 2013), and if the species survives, it occurs only in functionally extinct and isolated sub-populations (Timmins et al. 2020). Other Annamite endemic mammals — many of them also only discovered by science in recent decades — are following the same conservation trajectory as the saola (Timmins et al. 2016a, Tilker et al. 2019a). With concerted conservation actions, these species can still be saved from extinction, but the window for doing so is rapidly closing.

The large-antlered muntjac *Muntiacus vuquangensis* is one such Annamite endemic species that, like the saola, was only recently discovered by science and is now on the verge of extinction (Timmins et al. 2016b). The large-antlered muntjac's populations have collapsed as a result of widespread and intensive snaring across its range, and as of the last IUCN Red List assessment, only a few populations were confirmed to exist in Vietnam and Laos (Timmins et al. 2016b). Recently, a large-antlered muntjac was photographed in 2021 in Virachey National Park (NP), located in northeastern Cambodia, thus confirming a potential new population for the species, providing a significant westward range extension, and adding one more country to its global range (Pin et al. 2022). However, nothing is known about the species at the population level in Virachey NP, and this lack of information hinders the development of targeted conservation measures for the species and robust monitoring. Here, we report on the first assessment of the status and distribution of the large-antlered muntjac population in Virachey NP. We present our findings within an occupancy framework and discuss how our results can inform conservation strategies for the species.

2. MATERIALS AND METHODS

From February 23 to July 27, 2021, we set up 76 cameras (Bushnell HD Trophy Cam, Model 119719 CW) across 7 areas in Virachey NP (Fig. 1). A total of 63 cameras were placed in 7 pre-determined 3 × 3 km grids, each with 9 camera stations spaced 1.5 km apart. We set one camera per station. The cameras were set to take 3 photographs per trigger, separated

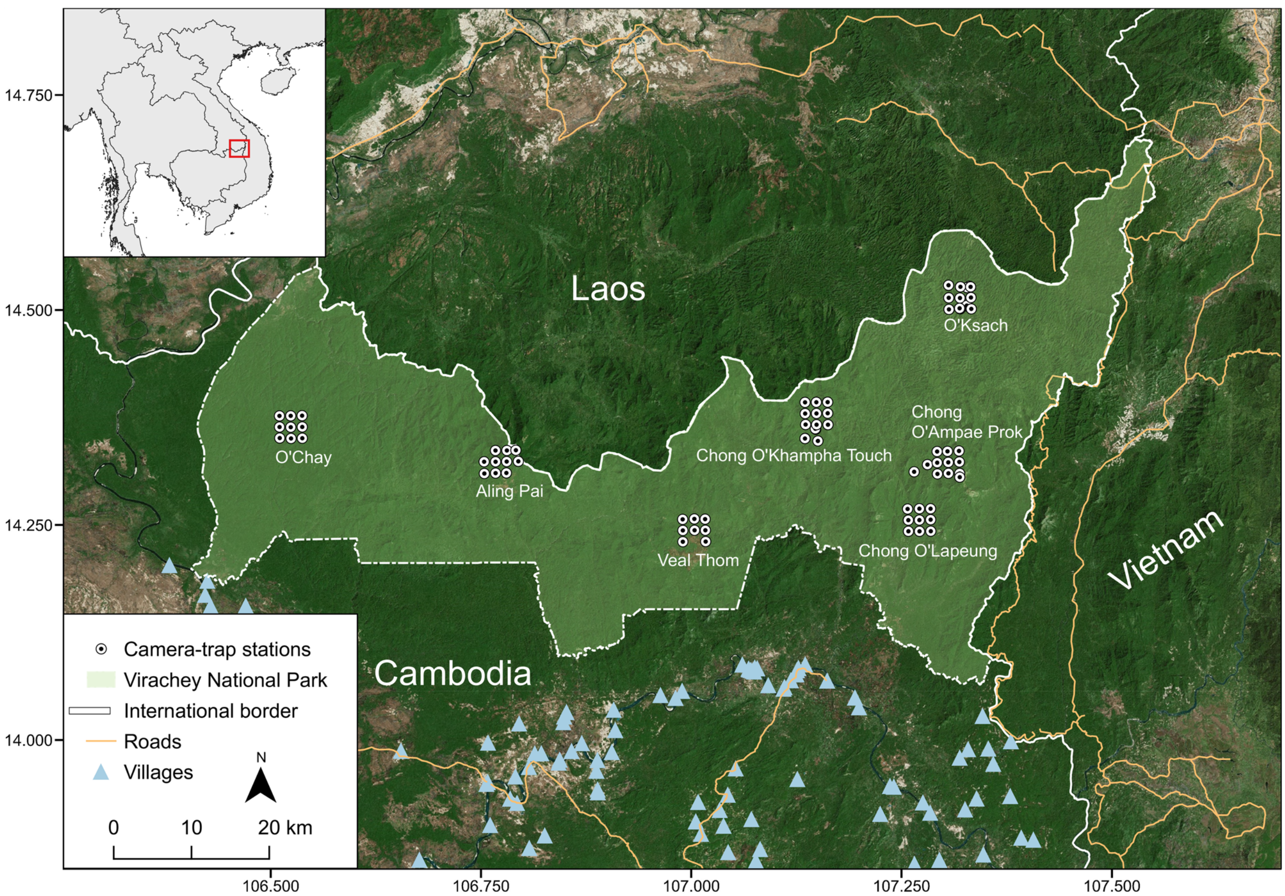

Fig. 1. Camera-trap locations in Virachey National Park, Cambodia

by 1 s intervals. The remaining 13 cameras were set in the general area of the 4 easternmost grids, but in a non-systematic way to target large mammals. These cameras were set to record 30 s of video per trigger. The systematic grid locations were chosen to provide good coverage across the park's major habitat and elevational gradients. A total of 46 cameras were placed in evergreen and semi-evergreen forest, 21 in bamboo forest, 7 in riparian habitats, and 2 in grasslands. Eleven cameras were placed at elevations over 1000 m above sea level (a.s.l.), 29 cameras in the 500—1000 m range, and the remainder in lowland areas below 500 m. Cameras were active for 154 d (mean = 94.31, SD = 34.04).

All muntjac photos were identified to the species level by 3 co-authors experienced in muntjac identification. Large-antlered muntjac and red muntjac were identified based on antler configuration in males, forehead coloration in females, and tail morphology for both sexes (Schaller 1996, Timmins et al. 1998). All muntjac that could not be confidently identified to species-level were left as unidentified and were not included in the analysis.

To assess the factors influencing large-antlered muntjac occurrence at the landscape scale, we collected both environmental and anthropogenic covariates: elevation, least-cost path (a metric for remoteness), terrain ruggedness index, slope, and roughness. Elevation, least-cost path, and terrain ruggedness index have been suggested as drivers of large mammal occurrence in similar studies in the Annamites (Tilker et al. 2020, Alexiou et al. 2022, Nguyen et al. 2022). In addition to terrain ruggedness index, both slope and roughness were explored as topographic variables that may influence muntjac occurrence. Elevation was derived from a SRTM 30 m digital elevation model (NASA JPL 2013). Least-cost path was calculated from the package movecost (Alberti 2019) using major roads near the study area (Google Earth 2023) as access points. Terrain ruggedness index, slope, and roughness were calculated in R v.4.0.2 (R Core Team 2020) using the package raster v.3.6.14 (Hijmans 2019).

We used a Spearman correlation test with a threshold of 0.6 to identify collinear covariates (Table S1 in the Supplement at www.int-res.com/articles/suppl/n053p493_supp.pdf). Our final covariate selection included elevation, least-cost path, and terrain ruggedness index. Slope and roughness were correlated to terrain ruggedness index and were excluded. We chose to use terrain ruggedness, as previous studies have indicated these covariates important in determining ungulate occurrence (Estes et al. 2011, Alexiou et al. 2022). All covariates were scaled and standardised to have a mean = 0 and SD = 1. Covariate station values were extracted using a 100 m radius buffer around stations.

All camera-trap photos and data preparation were processed using camtrapR v.2.2.0 (Niedballa et al. 2016). To prepare the data for the analyses, we created a species detection history and camera effort per station. The detection history shows whether the species was photographed or not during given time periods, defined as 'occasions', with '0' indicating that the species was not detected and a '1' indicating that it was detected in an occasion. Camera effort gives the number of active camera-trap days at a single station per occasion. We used a 5 d occasion length, resulting in 26 occasions for all stations. Values for camera effort varied in relation to the operational dates for each station.

We analysed camera-trap data using single species occupancy models (MacKenzie et al. 2002), implemented within a Bayesian framework in the package ubms v.1.1.0 (Kellner et al. 2022). We included camera effort *a priori* on detection probability to account for uneven sampling effort in the occasions. To select covariates for occupancy, we ran models with all possible covariate combinations and ranked models using expected log pointwise predictive density (elpd). We considered a model to be less important than the top model if the absolute value of the difference in elpd was greater than the standard error of that difference (Kellner 2021). We considered covariates to have strong support if the 95% Bayesian confidence intervals of the beta coefficients did not overlap zero. We estimated occupancy per station and then used averaged station estimates per camera-trapping area to predict zone-specific occupancy estimates. All models used non-informative priors, and we assessed convergence by confirming that all Rhat statistics were equal to 1.

3. RESULTS AND DISCUSSION

In total, we obtained 36 independent large-antlered muntjac detections (independence threshold = 30 min) across 6 stations in 2 zones (20 detections in zone O'Ksach and 16 detections in zone O'Ampae Prok). All records came from the northeastern part of the national park, close to the tri-border area with Vietnam and Laos. We recorded both male and female muntjac in both zones. Large-antlered muntjac records spanned an elevational range between 660 and 1308 m, with more than half of the records occurring above 1000 m elevation. Our top model included elevation and least-cost path on occupancy (Table 1; Table S2). Elevation showed a positive relationship with occupancy and a negative relationship with least-cost path, indicating that large-antlered muntjac occurrence is higher in remote areas with higher elevation (Fig. 2). Figs. S1–S3 provide additional information on the covariates and model used.

Table 1. List of models ranked by expected log pointwise predictive density (elpd). Models included camera effort *a priori* on detection probability (p) and all possible combinations of site covariates on occupancy probability(ψ). Models were considered to have less support than the top model if |Δelpd| > SE(Δelpd)

Model	elpd	Δelpd	SE(Δelpd)
p(camera effort) ψ(Elevation+Least-cost path)	−76.6102	0	0
p(camera effort) ψ(Elevation+Terrain ruggedness index+Least-cost path)	−77.0626	−0.4524	0.2421
p(camera effort) ψ(Least-cost path+Terrain ruggedness index)	−81.5461	−4.9359	2.3347
p(camera effort) ψ(Least-cost path)	−81.547	−4.9368	2.453
p(camera effort) ψ(Elevation)	−81.9517	−5.3415	2.0282
p(camera effort) ψ(Elevation+Terrain ruggedness index)	−82.698	−6.0878	2.1826
p(camera effort) ψ(Terrain ruggedness index)	−85.6272	−9.0171	3.4361
p(camera effort) ψ(.)	−86.448	−9.8378	3.8804

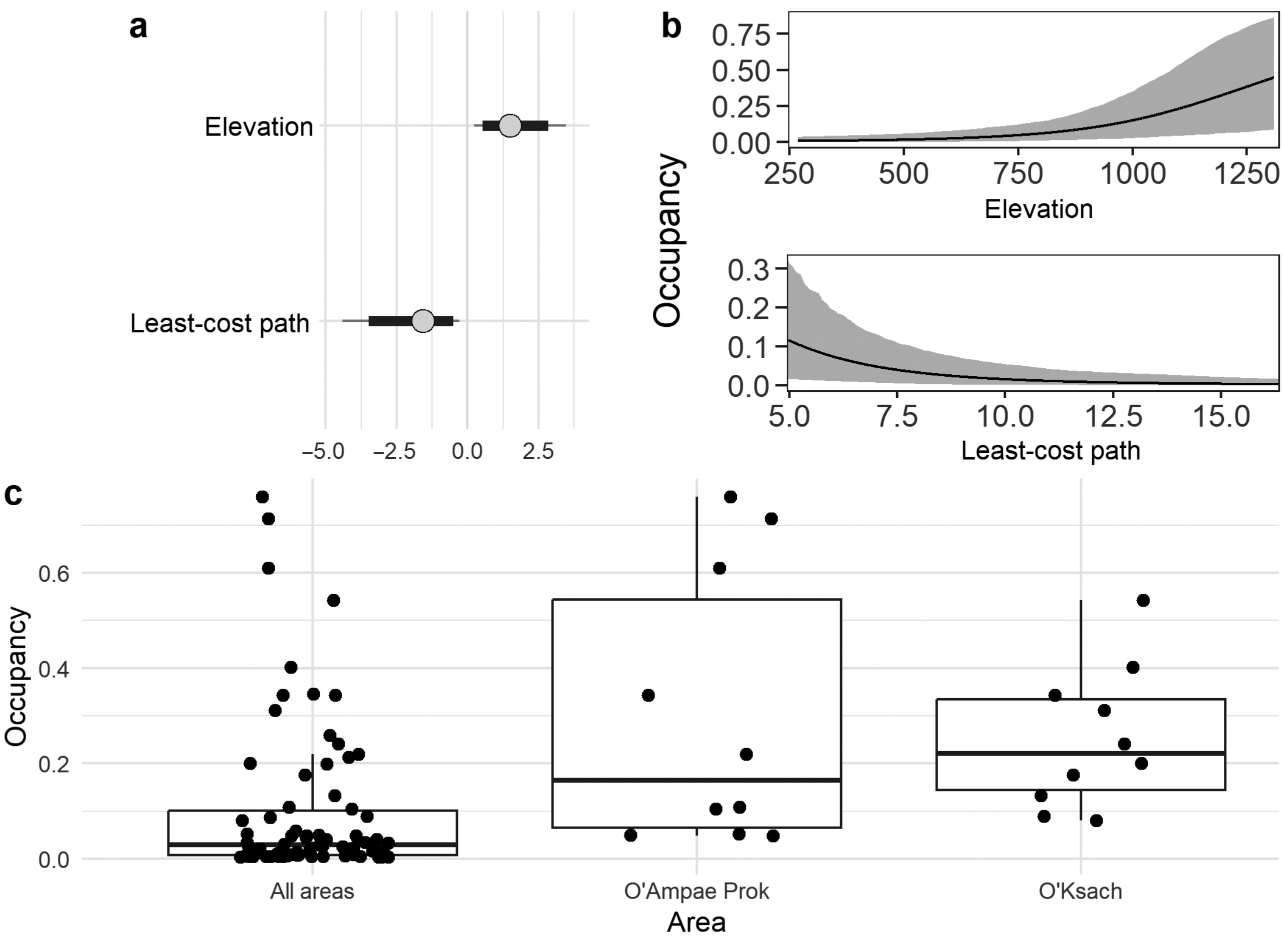

Fig. 2. Beta coefficients, response curves and occupancy estimates for large-antlered muntjac using elevation and least-cost path covariates in the top model. (a) Inner and outer intervals represent 95 and 99% confidence intervals respectively. (b) Shades in response curves indicate 95% confidence intervals. (c) Box plots show occupancy probability in camera-trapping grids in Virachey National Park where large-antlered muntjac was detected (all grids, O'Ampae Prok or O'Ksach zone). The horizontal line shows the median value for predicted occupancy, the upper and lower limits of the box show upper and lower quartiles, and the whiskers show minimum and maximum values. The jitter points show predicted occupancy at the stations

Large-antlered muntjac occupancy varied among camera-trapping areas (Fig. 2). Mean ± SD occupancy was estimated to be 0.1 ± 0.17 across all zones. The highest estimated mean occupancy occurred in the 2 zones where the species was detected: O'Ampae Prok (0.30 ± 0.29) and O'Ksach (0.25 ± 0.15). The estimated occupancies for the other zones without large-antlered muntjac detections were, as expected, much lower and close to zero.

Our results provide first insights into the status and distribution of large-antlered muntjac in Cambodia. The fact that we recorded the species in 2 out of 9 camera-trapping grids indicates that the species has a patchy distribution within Virachey NP. Such a finding is consistent with Pin et al. (2022), who obtained a single record of the species across an area of approximately 160 km^2. We believe it is likely that the disjunct distribution of large-antlered muntjac in the protected area, and its relative rarity, is due to a combination of ecological factors and hunting pressure.

Our covariate relationships provide some support for this claim. We found that large-antlered muntjac occurrence was positively correlated with elevation and remoteness. Changes in elevation often correspond to changes in habitat, and it is possible that such a habitat gradient underlies the relationship that we found with elevation in our models. Similarly, the fact that large-antlered muntjac occurrence was positively impacted by remoteness may indicate that the species has been hunted out, or its populations depleted, in easier to access areas of the national park. The correlation between large-antlered muntjac occupancy and remoteness is consistent with a study in Laos that also found that large-antlered muntjac occurrence increased in more difficult to reach areas (Alexiou et al. 2022).

The most welcome news from our study was the confirmation that there is a population of large-antlered muntjac in Virachey NP. Moreover, the fact that we recorded multiple individuals from both sexes as well as a fawn indicates that it is a breeding population. The confirmation of a Cambodian population of large-antlered muntjac is helpful for the conservation of the species. With the near extirpation of the species from Vietnam, and only a small number of confirmed populations in Laos (Timmins et al. 2016b), this additional population provides another lifeline for its survival. With the exceptionally high levels of unsustainable hunting in Vietnam, in particular (Timmins et al. 2016b), it is likely that the populations in Cambodia and Laos will only become more important in years to come.

To protect the large-antlered muntjac in Virachey NP, it will be imperative to reduce illegal hunting, which in Indochina is primarily accomplished through the setting of wire snares (Gray et al. 2021). It is likely that snaring is a threat to the species in Virachey NP; a number of studies in recent years have documented the negative impacts of snaring on mammal communities in the region (Rasphone et al. 2019, Tilker et al. 2019b, Groenenberg et al. 2023), and all indications are that Virachey NP is also undergoing snaring to supply the commercial wildlife trade. As pointed out by Pin et al. (2022), reducing snaring levels will be difficult to implement in practice; to date, few protected areas in the region have shown demonstrable reductions in snaring pressure. Nonetheless, we recommend that snare reduction actions be implemented as a matter of urgency to protect the large-antlered muntjac population in Virachey NP. To do this, it will be necessary to strengthen the number of ranger teams and improve their capacities for effective law enforcement.

Fortunately, there is some foundation for scaling up protection efforts in Virachey NP. Although the protected area has received little conservation attention in recent years — and was widely regarded as a so-called 'paper park' — conservation NGOs are now re-engaging with Virachey NP to strengthen its management. Such engagement will be crucial for protecting large mammals that are present in the protected area, especially in light of increased pressures that the park is likely to experience in the near future. Although the protected area's remoteness and rugged terrain have to some extent buffered it against the worst of the pressures that have affected much of the rest of Cambodia, as accessibility and rapid development spreads across the region, it is likely that pressures on Virachey NP will become increasingly acute in the absence of robust management.

The large-antlered muntjac population in Virachey NP could also play a role in *ex situ* plans for the species. Recently, conservation scientists have called for the establishment of a conservation breeding population of large-antlered muntjac as a priority for its conservation (Timmins et al. 2016b). It would make sense to include the Virachey NP population as a potential source for *ex situ* conservation breeding. From our camera-trapping data, we know that the species is present in detectable numbers in at least 2 areas of the national park; this situation stands in sharp contrast to Vietnam, where numbers are so low (Timmins et al. 2016b) that capture will be difficult, and perhaps unfeasible.

Our results provide the first robust information on the status and distribution of large-antlered muntjac in Cambodia. However, this information will only be effective if it is used by stakeholders to inform on-the-ground actions. We urge conservationists to follow up with *in situ* and *ex situ* conservation actions as a matter of the highest priority. Failure to proactively protect the Virachey population will put the species one step closer to extinction.

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