Disentangling vertebrate spatio-temporal responses to anthropogenic disturbances: evidence from a protected area in central Myanmar

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Abstract Urbanization of natural landscapes and increasing human populations have brought people and our companion animals into closer contact with wildlife, even within protected areas. To provide guidance for human–wildlife coexistence, it is therefore critical to understand the effects of anthropogenic disturbances and how well native wildlife species survive in human-dominated landscapes. We investigated the spatio-temporal responses of 10 vertebrate taxa, with an emphasis on the Endangered Eld's deer *Rucervus eldii thamin*, to anthropogenic disturbances in Shwesettaw Wildlife Sanctuary, Myanmar. We quantified anthropogenic disturbances as distance from human settlements, distance from a highway, and the presence of people and free-ranging dogs *Canis familiaris*. Anthropogenic disturbances had stronger negative impacts on the detection of native wildlife species than on occupancy. Eld's deer avoided areas close to human settlements and showed low diel activity overlap with both people and dogs, although we found a positive association with human presence at the camera-trap sites. Five species exhibited lower diel activity overlap with people in the rainy season when human activity is the highest in our study area. All studied wildlife species shifted to nocturnal activity or did not show any clear activity pattern during the cool-dry season when the presence of dogs increased. The ecological and conservation impacts of dogs are underestimated in South-east Asia, particularly in Myanmar, and this case study highlights the impacts of dogs on the temporal use of habitat by wildlife and the need for better practices in the management of dogs within protected areas.

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Introduction

Widespread human activity and land-use change have affected wildlife greatly, disrupting animal distributions and activity patterns globally (Gaynor et al., 2018; Tucker et al., 2018; Nickel et al., 2020). Monitoring and evaluating the impacts of human activities are therefore fundamental for conserving biodiversity effectively (Christie et al., 2019). Protected areas are one of the most effective ways to protect wildlife from human pressures; however, approximately one-third of protected areas globally are under intense anthropogenic pressure from human population growth and the development of settlements within and surrounding protected areas (Wittemyer et al., 2008; Jones et al., 2018). Areas that have been set aside for conservation therefore warrant attention when investigating the impacts of anthropogenic pressures on wildlife (Broekhuis et al., 2019).

In addition, invasive carnivores such as domestic dogs *Canis familiaris* and cats *Felis catus* pose a significant threat to wildlife, even within protected areas (Gompper, 2014; Farris et al., 2017). Although cats are not efficient predators of large animals (Yen et al., 2019), dogs can be detrimental to larger-sized species through predation (Ritchie et al., 2014), driving behavioural changes (Banks & Bryant, 2007), competition (Vanak et al., 2014), hybridization (Leonard et al., 2014) and disease transmission (Furtado et al., 2016). These negative impacts could worsen as dog populations continue to grow with increasing human populations (Hughes & Macdonald, 2013).

Although the impacts of dogs on wildlife are relatively well documented in some regions, little is known regarding this matter in South-east Asia, the region reported to have the largest number of threatened species affected by dogs (Doherty et al., 2017). Empirical research on the impacts of dogs on wildlife in South-east Asia is scarce, with most of the current knowledge being based on anecdotal observations (Peh, 2010). This is true in particular in the Republic of the Union of Myanmar (hereafter Myanmar), where research on the ecological impacts of anthropogenic disturbances on wildlife is scarce (Cremonesi et al., 2021).

Animal responses to a particular anthropogenic disturbance depend on the relative constancy or regularity of the disturbance in space and time; however, efforts to disentangle these disturbance types remain limited (Nickel et al., 2020). Thus, it is crucial to integrate multiple disturbance types when evaluating the impacts of anthropogenic activities on wildlife. We therefore conducted this study to examine how different vertebrate taxa living in a human-dominated protected area in Myanmar respond to anthropogenic disturbances (distance from human settlements, distance from a highway road and the presence of people and free-ranging dogs) in space and time. The vertebrate taxa in our study were Eld's deer *Rucervus eldii thamin*, northern red muntjac *Muntiacus vaginalis*, wild boar *Sus scrofa*, golden jackal *Canis aureus*, rhesus macaque *Macaca mulatta*, common palm civet *Paradoxurus hermaphroditus*, small Indian civet *Viverricula indica*, Burmese hare *Lepus peguensis*, Irrawaddy squirrel *Callosciurus pygerythrus* and red junglefowl *Gallus gallus*.

This investigation provides novel information on the spatio-temporal responses of Eld's deer to anthropogenic disturbances, which could be useful for the development of conservation strategies in our study area, home to the largest remaining population of this endemic species (Thu et al., 2019). We hypothesized that the occupancy and detection probability of native wildlife species would increase with increasing distance from human settlements and roads and decrease with the presence of people and dogs within Shwesettaw Wildlife Sanctuary. We also predicted that wildlife diel activity would exhibit seasonal variations in response to the seasonal diel activity of both people and dogs.

Study area

Shwesettaw Wildlife Sanctuary is in the Magwe Region of the central dry zone, the second most populated area of Myanmar (Fig. 1). The Sanctuary was established in 1940 to conserve the dry-zone ecosystem of Myanmar, especially the habitat of Eld's deer. It encompasses an area of 552.7 km² at altitudes of 52–565 m. As part of the typical dry zone, this area receives low rainfall (c. 775 mm per annum) and can experience high temperatures (c. 45°C). The land cover is of four types: open/degraded forest (132.6 km²); other wooded land/scrub and grassland (318.7 km²); agriculture, settlements and other anthropogenic areas (100.4 km²); and water (1.1 km²; Thu et al., 2019).

Since 2010 the Sanctuary has included 88.4 km² of military area for a troop base in the north-east. Thus, the northern and eastern parts of the Sanctuary are occupied mostly by human settlements and agricultural land. The Sanctuary is affected by both large-scale (e.g. permanent human settlements, permanent cultivation) and small-scale (e.g. hunting for subsistence and wildlife trade, shifting cultivation) human activities, with c. 44 villages located around the edges of the Sanctuary (Rao et al., 2002).

Methods

We deployed 80 camera traps (Yianws L710-940; Yianws, Shenzhen, China) in the Sanctuary during September 2017–October 2018. We could use only 53 camera traps for our final analysis because seven were burnt by wildfire and 20 malfunctioned. We set up the camera traps for year-round deployment, checking them every 3 months to replace the batteries and, when necessary, to clear understory growth to reduce false triggers and the obstruction of photographs by vegetation. The distance between any pair of cameras was at least 700 m, with placement designed to maximize geographical coverage. All of the camera traps were placed at animal trails, saltlicks, small streams or water holes where signs of animals were evident. We attached the cameras to trees 0.5–2.0 m above ground, depending on topography and vegetation cover, to ensure that animals would be clearly visible in the photographs. The minimum refractory period between two successive triggers was set to 5 s, with each trigger causing the cameras to take three consecutive images. We did not use bait and all cameras were set to work continuously.

We recorded the locations of the camera traps with a GPS and all of the photographs included a timestamp. We obtained geospatial data of the highway, towns and villages in the study area from the Myanmar Information Management Unit. Hereafter we use the term 'settlements' for both towns and villages. We considered the following four environmental covariates at each camera site: (1) distance from the highway (m); (2) distance from human settlements (m); (3) human presence; and (4) free-ranging dog (hereafter 'dog') presence. We measured the Euclidean distances of each camera station from the highway and settlements with *ArcGIS 10.7* (Esri, Redlands, USA). These averaged 4.55 ± SD 3.82 km and 9.33 ± SD 4.47 km, respectively.

Analysis

We considered consecutive images of the same species, including people and dogs, taken more than 0.5 h apart at the same camera station as independent events (O'Brien et al., 2003). We calculated the relative abundance index for each species as the number of independent events divided by the number of trap-days, multiplied by 100 (O'Brien et al., 2003). We computed the naïve occupancy for each species as the number of sites at which the species was trapped

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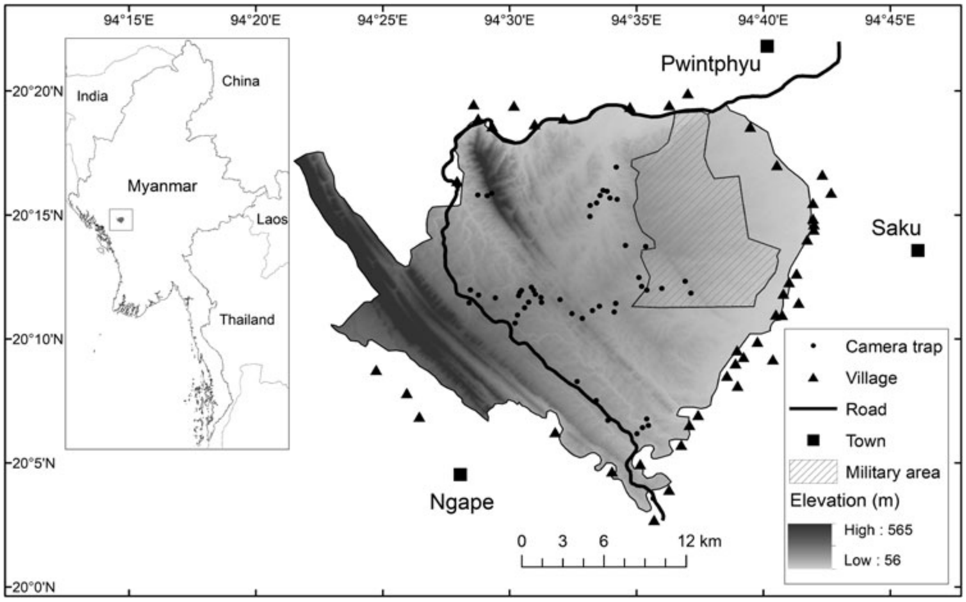

FIG. 1 Shwesettaw Wildlife Sanctuary in Myanmar, indicating the location of the camera traps.

divided by the total number of sites (n = 53) (Rovero et al., 2014). To evaluate survey effort, we built a rarefied species accumulation curve using the *vegan* package in *R 3.6.1* (Gotelli & Colwell, 2001).

We performed an occupancy analysis using the *unmarked* package in *R* for the 10 species that were detected in > 30 independent events (Fiske & Chandler, 2011). Occupancy (Ψ) is defined as the proportion of camera-trap sites where a species was expected to occur and detection probability (p) is defined as the likelihood of detecting an individual or species during a sampling occasion (MacKenzie et al., 2006). For each species we constructed detection/non-detection matrices of sites, grouping 10 consecutive camera-trap days into one survey occasion to reduce zero inflation in the dataset (Alexander et al., 2016; Boron et al., 2019). This resulted in 36 sampling occasions for each species. We tested for collinearity amongst the four covariates using a threshold value of Pearson's $r = 0.5$, and found none of the covariates to be highly correlated. Prior to the analysis we standardized all covariates to have a mean of zero and unit variance. We used the Akaike information criterion (AIC) and model selection to rank competing models and reported those with $\Delta AIC < 2.0$ (Burnham & Anderson, 2002). We calculated the relative importance of the model parameters using the *AICmodavg* package in *R* (Mazerolle, 2013).

To examine any temporal relationships between native wildlife, people and dogs, we investigated seasonal changes in diel activity overlap. Myanmar has three seasons: the cool-dry season (November–February), the hot-dry season (March–May) and the rainy season (June–October). We first calculated the number of independent camera-trap captures of people and dogs in each season, to examine seasonal activity variation using ANOVA. We then estimated the levels of diel activity overlap of native wildlife species with people and dogs in each season. We used a non-parametric circular kernel-density function and calculated a coefficient of overlap (Δ) to measure the extent of overlap between two kernel-density estimates (Ridout & Linkie, 2009). Overlap was assumed to be the area falling under both density curves. Δ ranges from 0 (no overlap) to 1 (complete overlap; Ridout & Linkie, 2009). We used Δ_4 for large samples (> 75 camera-trap records), otherwise we used Δ_1 (Meredith & Ridout, 2018). We considered Δ values 0.80–1.00, 0.50–0.79 and 0.00–0.49 to be high, medium and low/no levels of overlap, respectively (Lynam et al., 2013). We calculated 95% CIs of each overlap index using smoothed bootstrapping with 10,000 resamples, using the *overlap* package in *R* (Ridout & Linkie, 2009).

Results

Trapping effort and species composition

We obtained a total of 4,528 independent events from 16,444 camera-trap days, 87.0% of which were wild native mammals, 2.3% birds, 8.4% people and 2.3% dogs. We recorded a total of 16 native wildlife species representing 11 families (see Supplementary Table 1 for full details). The greatest number of detections were for the northern red muntjac, Eld's deer and wild boar (with 2,060, 953 and 421 independent events, respectively). We recorded 372 and 103 independent events of people and dogs, 10 of which were co-occurrences. The randomized species accumulation curve (Fig. 2) showed that we reached the species accumulation plateau with our sampling effort.

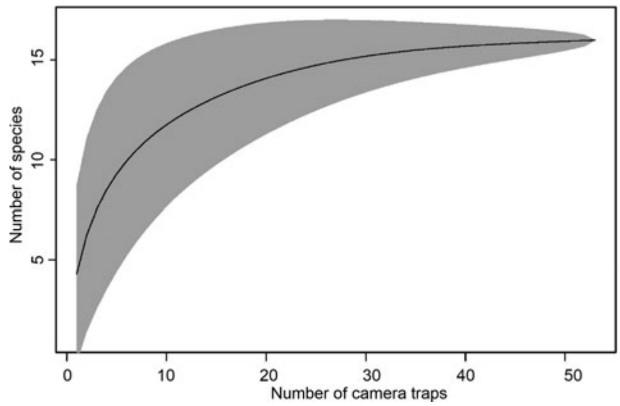

FIG. 2 Randomized species accumulation curve based on the number of camera traps in Shwesettaw Wildlife Sanctuary, Myanmar (Fig. 1). Shaded area indicates the 95% CI.

Effects of disturbance on occupancy and detection probability

Detection probability ranged from 0.068 for the common palm civet to 0.488 for the Irrawaddy squirrel, and occupancy ranged from 0.008 for the Irrawaddy squirrel to 0.934 for the northern red muntjac. The null model was not supported for any of the species and at least one covariate was retained as influential for species occupancy and detection probability (Table 1). Details of the model selection for each species are shown in Supplementary Table 2. Occupancy of Eld's deer increased with distance from human settlements, whereas the occupancy of northern red muntjacs increased close to settlements (Table 1, Supplementary Figs 1 & 2). The occupancies of wild boars, common palm civets, small Indian civets and red junglefowl decreased with distance from roads, whereas the occupancy of golden jackals increased with distance from roads (Table 1, Supplementary Figs 3–7). Only red junglefowl and Burmese hares had a positive relationship between occupancy and human presence (Table 1, Supplementary Figs 6 & 8). The presence of dogs did not have a significant effect on the occupancy of native wildlife species (Table 1). Human settlements had a strong negative effect on the detection probabilities of all of the studied species except for golden jackals and Eld's deer (Table 1, Supplementary Figs 1–10). Distance from roads had a strong positive effect on the detection probabilities of northern red muntjacs, wild boars, common palm civets, golden jackals and red junglefowl (Table 1). Human presence had a positive effect on the detection of wild boars, Eld's deer and Burmese hares, and a negative effect on the detection of northern red muntjacs, golden jackals and red junglefowl. The presence of dogs had a positive effect on the detection of northern red muntjacs, golden jackals and red junglefowl and a negative effect on the detection of wild boars, Eld's deer and Irrawaddy squirrels (Table 1).

Activity overlap between native wildlife species, people and free-ranging dogs

People and dogs were active mainly during the daytime. People had activity peaks at 06.00–11.00 and 12.30–14.30, and dog activity peaked at 05.30–11.30. Dogs did not exhibit significant seasonal variation in activity level ($P = 0.74$) with $8.5 \pm$ SD 4.0 ($n = 34$) independent captures in the cool-dry season, $8.3 \pm$ SD 2.5 ($n = 33$) independent captures in the hot-dry season and $7.0 \pm$ SD 2.7 ($n = 35$) independent captures in the rainy season. The activity level of people also had no significant seasonal variation ($P = 0.06$), with $19.8 \pm$ SD 7.3 ($n = 79$) independent captures in the cool-dry season, $26.7 \pm$ SD 3.1 ($n = 80$) independent captures in the hot-dry season and $35.8 \pm$ SD 10.9 ($n = 179$) independent captures in the rainy season. All 10 wildlife species had seasonal differences in level of diel activity overlap (Δ) with both people and dogs (Figs 3 & 4, Table 2), with a lower overlap with dogs during the cool-dry season, when the mean activity level of dogs was highest (Fig. 4, Table 2). Eld's deer, northern red muntjacs, rhesus macaques, red junglefowl and small Indian civets showed lower diel activity overlap with people during the rainy season, when the mean activity level of people was highest (Fig. 3, Table 2). Diel activity overlap with people, however, was higher in the rainy season for wild boars, golden jackals, Burmese hares, Irrawaddy squirrels and common palm civets (Fig. 3, Table 2). None of the wildlife species had high levels of diel activity overlap with either people or dogs except for the red junglefowl, which showed high levels of diel activity overlap with people in both the hot-dry season ($\Delta = 0.84$) and the rainy season ($\Delta = 0.82$; Table 2).

Discussion

This study improves our understanding of how various anthropogenic disturbances can affect wildlife spatio-temporal habitat use and raises concerns regarding the potential ecological impacts of dogs in South-east Asia, particularly in Myanmar. We found that the proximity of settlements and a road had significant effects on the occupancies and detection probabilities of 10 wildlife species, and the presence of dogs had severe effects on the activity patterns of these wildlife species. Of the various forms of potential disturbance analysed, settlements had a strong negative impact on the detection probabilities of wildlife other than for golden jackals (positive effect) and Eld's deer (no effect; Table 1). Urbanized areas represent long-term and spatially constant sources of disturbance (Ordeñana et al., 2010), which wildlife might avoid because of the associated noise, light and risk of hunting or predation by domestic carnivores (Yen et al., 2019). Contrary to our expectations, the detection and occupancy probability of five species (northern red muntjac, wild boar, common

TABLE 1 Summary of species-specific occupancy (Ψ) and detection probability (p) estimates for the 10 species most commonly detected by camera traps in Shwesettaw Wildlife Sanctuary, Myanmar (Fig. 1), ordered by decreasing estimated occupancy. Reported results are the mean values of predicted occupancy and detection probability from the final models. Significant outcomes of the effects of covariates on Ψ and p are indicated with their direction (positive or negative effect); a blank cell indicates no significant effect.

			p				Ψ			
Species	$p \pm$ SE	$\Psi \pm$ SE	Road	Settlement	People	Dogs	Road	Settlement	People	Dogs
Northern red muntjac *Muntiacus vaginalis*	0.435 ± 0.019	0.934 ± 0.042	–	+	–	+	–	–		
Wild boar *Sus scrofa*	0.161 ± 0.015	0.928 ± 0.095	–	+	+	–	–			
Rhesus macaque *Macaca mulatta*	0.102 ± 0.017	0.747 ± 0.239		+						
Eld's deer *Rucervus eldii thamin*	0.202 ± 0.013	0.829 ± 0.080			+	–		+		
Common palm civet *Paradoxurus hermaphroditus*	0.068 ± 0.017	0.542 ± 0.174	–	+			–			
Small Indian civet *Viverricula indica*	0.072 ± 0.018	0.026 ± 0.119		+			–			
Golden jackal *Canis aureus*	0.077 ± 0.022	0.145 ± 0.106	–	–	–	+	+			
Burmese hare *Lepus peguensis*	0.201 ± 0.042	0.063 ± 0.039		+	+				+	
Irrawaddy squirrel *Callosciurus pygerythrus*	0.488 ± 0.504	0.008 ± 0.017		+		–				
Red junglefowl *Gallus gallus*	0.125 ± 0.027	0.239 ± 0.134	–	+	–	+	–		+	

palm civet, small Indian civet and red junglefowl) increased near the highway. Food resources along roads bisecting forest ecosystems can attract wildlife, sometimes acting as ecological traps (e.g. Yamamoto-Ebina et al., 2016). In the case of Shwesettaw Wildlife Sanctuary, the highway is an asphalt road with low traffic density and wildlife roadkill has not been reported to be a common problem.

The hierarchical nature of occupancy models (Kéry, 2008) allowed us to identify that, in some cases, a type of disturbance had opposing effects on the occupancy and the detection probability of a species. For example, the occupancy of northern red muntjacs increased near settlements, whereas their detection probability decreased (Table 1), probably because this species has a stronger response to food availability than to human disturbance (Rahman et al., 2017). This suggests northern red muntjacs could be afraid of people and hence behave more elusively in their presence. Similarly, the detection probability of golden jackals was high close to settlements and roads, but their occupancy was low near roads. Golden jackals are versatile predators and opportunistic feeders (Lange et al., 2021), with broad diets that range from small mammals and rodents (Lanszki et al., 2010) to poultry and cattle (Raichev et al., 2013). Given its tolerance of people, the golden jackal seems to avoid human disturbance by adopting more elusive foraging habits (Suraci et al., 2019).

Where wildlife species are unable to avoid people spatially, they could avoid them in time (Carter et al., 2012; Gaynor et al., 2018). Contrary to our expectations, the presence of people in the forest had a positive effect on the detection of Eld's deer (Table 1). This could reflect an overlap in preferred habitats, which Eld's deer could compensate for by avoiding people temporally. Our results show that Eld's deer shifted to nocturnal activity during the rainy season, when human presence in the Sanctuary increased (Fig. 3). Similarly, a previous study found that Hainan Eld's deer became increasingly nocturnal after being translocated to a human-inhabited area (Pan et al., 2011). Although the presence of dogs had no effect on Eld's deer occupancy, it had a strong negative impact on their detection probability (Table 1). This suggests that Eld's deer increased their elusive behaviours in the presence of dogs. This is consistent with the reduced activity level of Eld's deer that we found in the cool-dry season, when the activity level of dogs increased (Fig. 4).

We observed wild boars to be highly tolerant of people, with their detection affected positively by human presence and no temporal avoidance of people (Fig. 3, Table 1). The activity level of wild boars seems to depend on location and seasonal conditions and to have considerable plasticity (Johann et al., 2020). Although macaques are also considered highly tolerant of people and are known to thrive even in densely populated urban areas (Priston & McLennan, 2013), we found higher detection of rhesus macaques with increasing distance from settlements. Moreover, macaques exhibited low temporal overlap with both humans and dogs (Figs 3 & 4), suggesting they used an avoidance strategy. Dogs can severely affect ground-dwelling birds (Hunt et al., 1996); however, we found higher detection of red junglefowl in areas with high dog presence. Red junglefowl might take advantage of the high temporal predictability of the activity level of dogs to avoid them

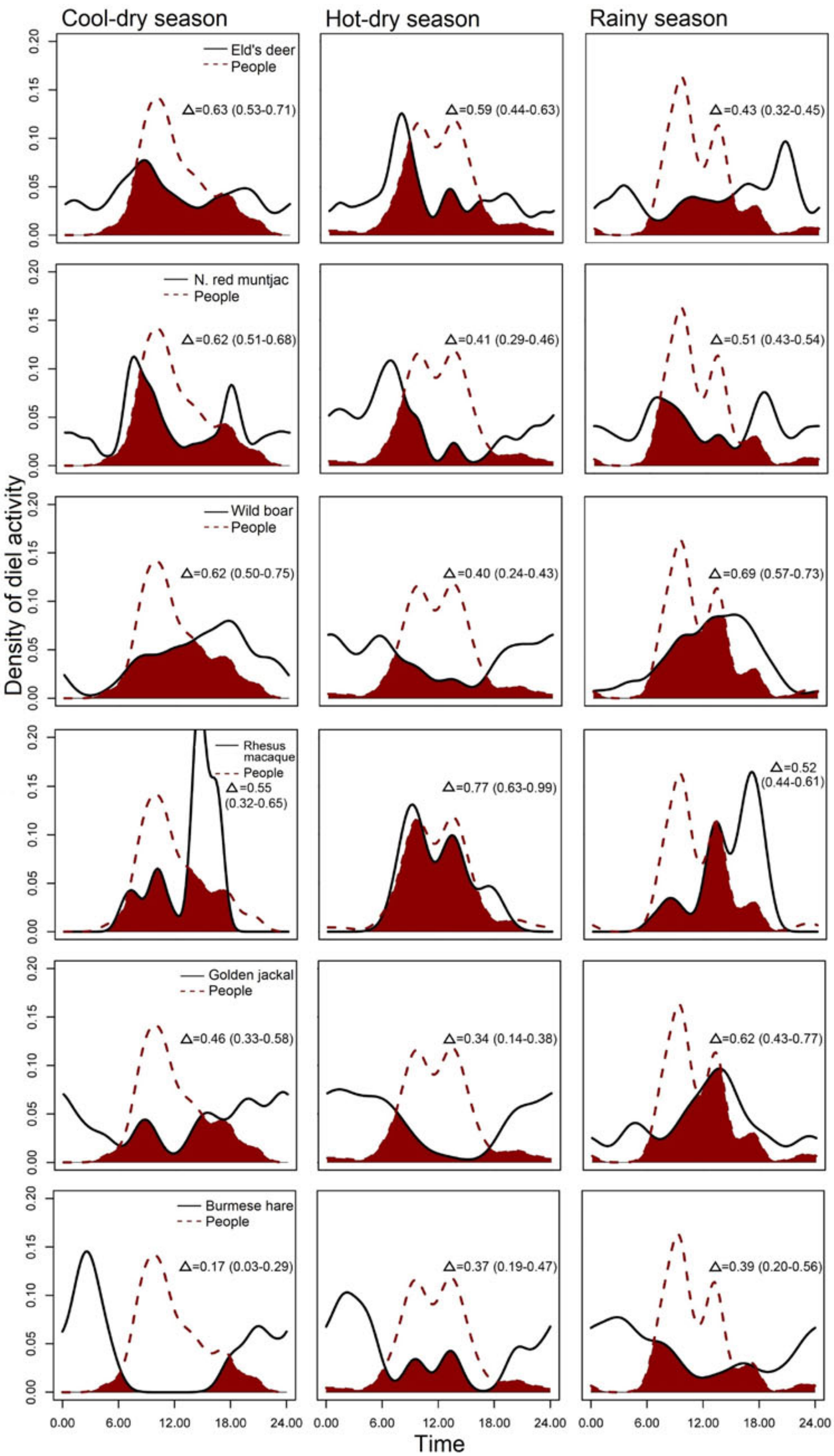

FIG. 3 The diel activity (Table 2) of six mammal species compared to that of people in the three seasons (cool-dry, hot-dry, rainy) in Shwesettaw Wildlife Sanctuary, Myanmar. The shaded area indicates overlap, and the coefficient of overlap (Δ; with 95% CI) is indicated in each case.

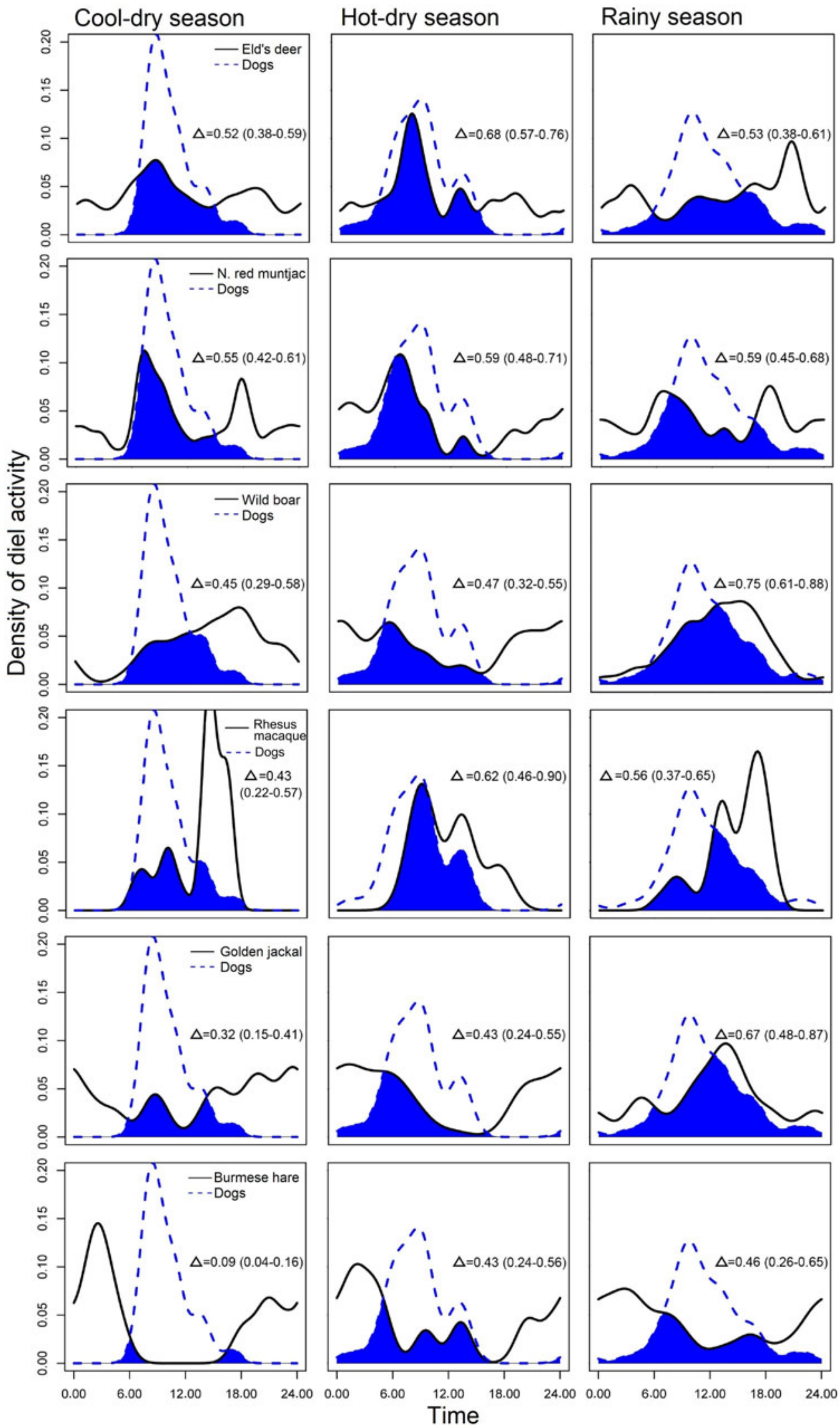

FIG. 4 The diel activity (Table 2) of six mammal species compared to that of dogs in the three seasons (cool-dry, hot-dry, rainy) in Shwesettaw Wildlife Sanctuary, Myanmar. The shaded area indicates overlap, and the coefficient of overlap (Δ; with 95% CI) is indicated in each case.

temporally. This is supported by the fact that red junglefowl did not show any clear activity pattern during the cool-dry season when the presence of dogs increased in the Sanctuary (Table 2).

Being nocturnal, the occupancies and detection probabilities of common palm civets and small Indian civets were not affected by the presence of people or dogs (Table 1). These civets, however, avoided dogs temporally (Yen et al.,

TABLE 2 The seasonal coefficient of overlap (with 95% CIs) for the 10 most commonly detected species with people and free-ranging dogs in Shwesettaw Wildlife Sanctuary, Myanmar (Figs 3 & 4). The cool-dry season is during November–February, the hot-dry season during March–May and the rainy season during June–October. Blank cells indicate no diel activity overlap.

	Overlap (95% CI) with people			Overlap (95% CI) with free-ranging dogs		
Species	Cool-dry season	Hot-dry season	Rainy season	Cool-dry season	Hot-dry season	Rainy season
Northern red muntjac	0.62 (0.51–0.68)	0.41 (0.29–0.46)	0.51 (0.43–0.54)	0.55 (0.42–0.61)	0.59 (0.48–0.71)	0.59 (0.45–0.68)
Wild boar	0.62 (0.50–0.75)	0.40 (0.24–0.43)	0.69 (0.57–0.73)	0.45 (0.29–0.58)	0.47 (0.32–0.55)	0.75 (0.61–0.88)
Rhesus macaque	0.55 (0.32–0.65)	0.77 (0.63–0.99)	0.52 (0.44–0.61)	0.43 (0.22–0.57)	0.62 (0.46–0.90)	0.56 (0.37–0.65)
Eld's deer	0.63 (0.53–0.71)	0.59 (0.44–0.63)	0.43 (0.32–0.45)	0.52 (0.38–0.59)	0.68 (0.57–0.76)	0.53 (0.38–0.61)
Common palm civet	0.24 (0.02–0.50)		0.27 (0.02–0.46)		0.24 (0.03–0.34)	0.33 (0.07–0.53)
Small Indian civet		0.38 (0.14–0.55)	0.07 (0.00–0.08)		0.38 (0.18–0.57)	0.12 (0.01–0.17)
Golden jackal	0.46 (0.33–0.58)	0.34 (0.14–0.38)	0.62 (0.43–0.77)	0.32 (0.15–0.41)	0.43 (0.24–0.56)	0.67 (0.48–0.87)
Burmese hare	0.17 (0.03–0.29)	0.37 (0.19–0.47)	0.39 (0.20–0.55)	0.09 (0.04–0.16)	0.43 (0.24–0.56)	0.46 (0.26–0.65)
Irrawaddy squirrel			0.76 (0.62–0.86)			0.79 (0.68–0.94)
Red junglefowl		0.84 (0.76–0.96)	0.82 (0.73–0.92)		0.63 (0.42–0.78)	0.78 (0.65–0.88)

2019), showing no activity overlap with them, particularly in the cool-dry season when the activity level of dogs was high. Burmese hares also avoided people temporally rather than spatially, as hares are mainly nocturnal (Rehnus, 2014). The presence of dogs can alter the distribution, occupancy and activity patterns of native wildlife in protected areas (Zapata-Ríos & Branch, 2016; Yen et al., 2019). Our results also showed that negative wildlife responses (i.e. avoidance in space and/or time) were stronger towards dogs than towards people, suggesting these species perceived dogs as the greater threat. In the Sanctuary we detected dogs at 43.4% of the camera traps and they comprised 2.3% of all independent captures. Although the current population size of dogs in Myanmar and its protected areas is unknown, the dog population is believed to be increasing with the increasing human population, as human and dog population sizes are strongly correlated (Hughes & Macdonald, 2013).

Our findings highlight the impacts of anthropogenic disturbances on wildlife conservation in protected areas and shed light on the understudied issue of the conservation impacts of dogs in South-east Asia. We found that vertebrates in a protected area of Myanmar altered their temporal and spatial patterns of habitat use in response to human disturbances, including the presence of dogs. Follow-up studies are necessary to better understand how these changes in the spatio-temporal patterns of habitat use translate into population dynamics, particularly of threatened species such as Eld's deer. Our results also indicate the need for better management practices regarding dog control and their presence in protected areas, as dogs have been reported to pose a threat to 188 threatened species worldwide (Doherty et al., 2017). Because people perceive dogs as working members of households (e.g. herding, guarding and hunting) in rural communities, at least in Myanmar, it is difficult to prohibit the presence of dogs completely within protected areas. To facilitate the support of local communities for dog population management, we suggest developing socially sensitive awareness campaigns on wildlife conservation and the potential negative impacts of dogs. Based on our findings, we recommend initiating a management programme to control dog presence in protected areas and creating a new regulation for managing and controlling domestic animals in buffer zones surrounding protected areas in Myanmar and other South-east Asian countries.

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Author contributions Conception and design: AMT, R-CQ, AC-A, THT; analysis and interpretation of data: AMT; writing: AMT; revision: AMT, R-CQ, AC-A.

Conflicts of interest None.

Ethical standards This research was conducted under the laws of Myanmar and with permission from Myanmar's Forest Department. This research and the use of images of people followed guidelines and protocols that assured and protected anonymity, and otherwise abided by the *Oryx* guidelines on ethical standards.

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