Use of trapeangs by Eld's deer *Rucervus eldii siamensis* in Siem Pang Wildlife Sanctuary, Cambodia

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មូលន័យសង្ខេប

ត្រពាំងមានសារសំខាន់សម្រាប់សត្វជាច្រើនប្រភេទដែលរស់នៅព្រៃរបោះនៅភាគខាងជើងនិងភាគខាងកើតនៃប្រទេសកម្ពុជា។ ជាពិសេសត្រពាំងផ្តល់ប្រភពទឹកដ៏សំខាន់សម្រាប់សត្វទំពារអៀង និងប្រភេទសត្វដទៃទៀត ដោយសារត្រពាំងកាន់តែខ្វះខាតទឹកខ្លាំងនៅរដូវប្រាំង។ យើងបានវាយតម្លៃវត្តមានរបស់សត្វក្ដាន់ *Rucervus eldii siamensis* ដែលជាសត្វជិតផុតពូជជាសាកលនៅត្រពាំងក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាងនៅភាគខាងជើងប្រទេសកម្ពុជា។ គោលបំណងរបស់យើងគឺមើលកំណើនវត្តមានសត្វក្ដាន់នារដូវប្រាំងដោយការដាក់ទឹកបន្ថែមក្នុងត្រពាំង ហើយយើងបានពិនិត្យមើលអន្ទាក់កាមេរ៉ានៅឆ្នាំ២០២១ និងឆ្នាំ២០២២ ដែលដាក់ពង្រាយចំនួន ២៤ នៅ ១២ ត្រពាំង (អន្ទាក់កាមេរ៉ាពីរក្នុងមួយត្រពាំង) នៅព្រៃរបោះក្នុងទីជម្រកសត្វព្រៃសៀមប៉ាង។ កម្រិតទឹកត្រូវបានរក្សានៅត្រពាំងចំនួន០៦នៃការសិក្សា ដោយម៉ាស៊ីនបូមទឹកប្រើថាមពលពន្លឺព្រះអាទិត្យដើម្បីប្រៀបធៀបជាមួយនឹងត្រពាំងចំនួន០៦ទៀតដែលមិនបានបន្ថែមទឹក។ យើងមិនបានរកឃើញភាពខុសគ្នាជាតំលៃស្ថិតិនូវចំនួនវត្តមានសត្វក្ដាន់រវាងត្រពាំងបន្ថែមទឹក និងត្រពាំងមិនបន្ថែមទឹកទេ ទោះបីការប្រើប្រាស់ត្រពាំងបន្ថែមកាន់តែច្រើនដោយសត្វក្ដាន់ត្រូវបានកត់ត្រានៅឆ្នាំទី២ក៏ដោយ។ លទ្ធផលរបស់យើងផ្តល់នូវព័ត៌មានអេកូឡូស៊ីអំពីសកម្មភាពសត្វក្ដាន់នៅត្រពាំង និងជួយក្នុងការសម្រេចចិត្តសម្រាប់ការគ្រប់គ្រងសត្វក្ដាន់នាពេលអនាគត។

Abstract

Waterholes (*trapeang* in Khmer) are important for a wide range of species inhabiting deciduous dipterocarp forests in northern and eastern Cambodia. In particular, they provide a critical source of water for ungulates and other species as this becomes increasingly scarce during the dry season. We evaluated visits by the globally Endangered Eld's deer *Rucervus eldii siamensis* to trapeangs in Siem Pang Wildlife Sanctuary, northern Cambodia. Our aim was to test if supplementary water provisioning would increase visitation rates of the deer during the dry season and we conducted camera trap surveys in 2021 and in 2022, deploying 24 camera traps at six pairs of trapeangs (two cameras per trapeang) in deciduous dipterocarp forests within the sanctuary. Water levels were maintained at six of our study trapeangs with solar water pumps to allow comparisons with our six control trapeangs. We did not find a statistically significant difference in the number of deer visits between the two groups of trapeangs, although greater use of supplemented trapeangs by the deer was recorded during the second year. Our results provide ecological information on the activity of Eld's deer at trapeangs and will aid decision-making for their future management.

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Introduction

Deciduous dipterocarp forests (DDF) are a unique ecosystem and species assembly found across the Mekong Basin in Southeast Asia, where high temperatures and pronounced seasonal precipitation patterns predominate (Pennington *et al*., 2009). These are characterized by a savanna landscape comprising a mix of deciduous trees (predominantly Dipterocarpaceae) and grasslands (Ratnam *et al*., 2011; Wohlfart *et al*., 2014). In northern and eastern Cambodia, DDF supports a wide range of important and endangered species, including Asian elephant *Elephas maximus*, banteng *Bos javanicus* and Eld's deer *Rucervus eldii*. This ecosystem is functionally distinct and evolved in response to abiotic factors (soil characteristics, seasonality and climate) and disturbances caused by herbivores or the frequent fires that occur during the dry season (Pletcher *et al*., 2022).

Waterholes, known as *trapeang* in Khmer, are an integral feature of DDF in Cambodia. These wetlands fill with water during the rainy season and typically dry out during the subsequent dry season months, creating patches of muddy substrates that provide ideal living or foraging conditions for a range of species, including critically endangered giant ibises *Thaumatibis gigantea* and white-shouldered ibises *Pseudibis davisoni* (Wright *et al*., 2010; Eang *et al*., 2021). They likely also provide a critical source of drinking water for ungulates such as Eld's deer during the peak dry season (Pin *et al*., 2018). Eld's deer is a large tropical cervid that historically occurred across DDF in Southeast Asia. The species has suffered a significant decline, with just two numerically significant units of wild animals now remaining, *R. e. thamin* in Myanmar and *R. e. siamensis* in Cambodia (Ladd *et al*., 2022a). In Cambodia, populations of the species have declined by over 90% since 2000 and while the most recent *IUCN Red List Assessment* in 2015 estimated 700 individuals remained in functionally isolated subpopulations (Gray *et al*., 2015a), the current population is likely less than 400 individuals (Ladd *et al*., 2022a).

Despite their importance, the ecological roles performed by trapeangs in DDF are increasingly disturbed by human activities such as land conversion to agriculture (Gray *et al*., 2015b) and ecological succession associated with the disappearance of the native wallowing megafauna (Eames *et al*., 2018). Climate change also represents a major threat, as the expected changes in rainfall patterns and increased temperatures associated with global warming will significantly impact water resources and water availability in Cambodia and this in turn impact the biodiversity and ecological balance of wetlands, as well as the livelihoods of communities that depend on them (Oeurng *et al*., 2019). Further, Cambodia's climate is affected by the El Niño–Southern Oscillation (ENSO) (Thirumalai *et al*., 2017), which usually returns every two to seven years (Climate Prediction Center, 2023). The warming phase El Niño causes hotter and dryer conditions than usual during the dry season months from November to April, and the frequency of extreme El Niño events is expected to increase due to climate change (Nicholls *et al*., 2005; Wang *et al*., 2019). For instance, the 2014–2016 episode culminated in a severe drought in Cambodia that affected both agriculture and wildlife, with a significant toll on animal life (Crothers, 2016).

Ecological management of trapeangs and ensuring their resilience in the face of climate change is of paramount importance given the number of species that depend on them (Timmins, 2012). Ungulates vary in their requirements for water, but as most species show some dependency towards specific drinking locations, water availability in seasonal ecosystems with temporal and/or spatial water scarcity is important for maintaining ungulate populations (Western, 1975; Hayward & Hayward, 2012; Montalvo *et al*., 2019). As such, creation of artificial waterholes or modifications to existing waterholes are integral to wildlife (particularly ungulate) conservation strategies in tropical savannah and dry forest ecosystems (Chamaillé-Jammes *et al*., 2007; Smit *et al*., 2007; Dar *et al*., 2012; Weeber *et al*., 2020). To this end, several pilot projects have been undertaken in Cambodia in recent years to determine whether such efforts are beneficial to local wildlife and how they might impact the use of trapeangs by globally threatened large ungulates and waterbirds. Trial modifications include the deepening of existing trapeangs on the assumption that they would hold water for longer periods during the dry season (Gray *et al*., 2015b), or by artificially creating new waterholes. These suggest that artificial deepening of natural trapeangs is effective in increasing water availability during the dry season, although the effects of this on local wildlife have yet to be investigated.

Pin *et al*. (2018) found that size and depth characteristics of trapeangs in eastern Cambodia was positively correlated with visitation by threatened waterbird species. Notwithstanding this, the influence of waterholes characteristics on their use by other wildlife species requires further investigation as trapeangs in DDF are likely of particular importance for wildlife in these ecosystems. In Siem Pang Wildlife Sanctuary in northern Cambodia, 66 trapeangs have been modified by manual or mechanical excavation to date and six trapeangs have been equipped with solar pumps that draw water up from the water table, including four which have been deepened (Rising Phoenix, unpubl. data).

SPWS likely hosts the largest remaining population of *R. e. siamensis* (Ladd, 2022; Ladd *et al*., 2022b), although this is particularly vulnerable to illegal hunting. During the 2016 drought, almost all of the trapeangs known in Siem Pang Wildlife Sanctuary dried out whereas the sole waterhole that retained water (trapeang Chambork), was increasingly visited by Eld's deer due to the scarcity of water elsewhere (as indicated by deer trails). Local hunters erected *machans*—wooden platforms in trees—at this trapeang from which to shoot the animals. To reduce the risk of hunting in future, we selected six waterholes throughout the DDF in SPWS for a pilot project aimed at providing permanent water sources. To this end, we created bore-wells at the six waterholes and equipped these with solar pumps in January 2021. The pumps were tasked with maintaining water in the trapeangs during the dry season (and were turned off during the wet season), drawing water from the water table 30–50 m below ground level. Consequently, the purpose of our study was to test if artificial provisioning of water at the six trapeangs during the dry season increased their visitation and use by Eld's deer relative to unmodified trapeangs.

Methods

Study area

Siem Pang Wildlife Sanctuary (SPWS) is a forest landscape mosaic with wetland elements and covers 130,000 ha in northern Cambodia. Deciduous dipterocarp forests account for 50% of the sanctuary, whereas semi-evergreen forests account for another 40%, with the remainder comprising degraded forests or grasslands (8%) and riverine habitats (2%) (BirdLife International Cambodia Programme, 2012). In Cambodia, DDF is characterized by a pronounced seasonal monsoon cycle, with alternating dry and wet seasons (Fan & Luo, 2019). Mean annual precipitation in SPWS is around 1,300 mm according to models, but rainfall is highly seasonal with most occurring during the wet season (mean 1,200 mm) from May to October and less than 100 mm during the dry season from November to April (Global Modelling & Assimilation Office, 2015). Over 200 trapeangs have been documented in SPWS (Rising Phoenix, unpubl. data). Most dry out during the dry season whereas others usually maintain water throughout the year. Domestic cattle *B. taurus* and water buffalo *Bubalus bubalus* from nearby villages roam freely in DDF within the wildlife sanctuary. The largest wild mammals occurring in these are Eld's deer, wild pig *Sus scrofa* and northern red muntjac *Muntiacus vaginalis*, with other large ungulates such as gaur *B. gaurus*, banteng *B. javanicus* and sambar deer *Rusa unicolor* now largely restricted to the semi-evergreen forests. Asian elephants occur east of the Sekong River and wild water buffaloes *B. arnee*, if formerly present, are now extirpated (Loveridge *et al*., 2018). Because waterholes provide a source of water for domestic ungulates and food (fish and frogs) for local communities, humans and their domestic dogs *Canis familiaris* are also frequent visitors (Ladd *et al*., 2023).

Study sites

Our study was conducted in trapeangs situated within DDF inside the wildlife sanctuary. The six trapeangs with pumps installed were paired with six control trapeangs without pumps (Fig. 1). Where possible, the paired trapeangs were selected with similar characteristics to the trapeangs with pumps. This included consideration of the surrounding vegetation and trapeang size. Paired trapeangs were at least 400 m and a maximum of 1,300 m apart (Fig. 2, Table 1). Water was maintained in the trapeangs with pumps throughout the dry season, whereas the other trapeangs were allowed to dry out naturally.

Camera trapping

We deployed camera traps (BTC-6PXD Dark Ops, Browning Trail Cameras, New South Wales, Australia) at 12 trapeangs in 2021 (six supplemented & six controls) and 11 trapeangs in 2022 (six supplemented & five

Table 1 Distance between paired trapeangs in Siem Pang Wildlife Sanctuary.

Supplemented	Control	Distance (km)
Angkrong	Thmor	0.9
Kdoeung	Umpiel	0.4
Khmun	Ktum	1.2
Lumporn	Trakoun	0.6
Lumtier	Thmat Kon	1.3
Thmea	Kontout	0.8

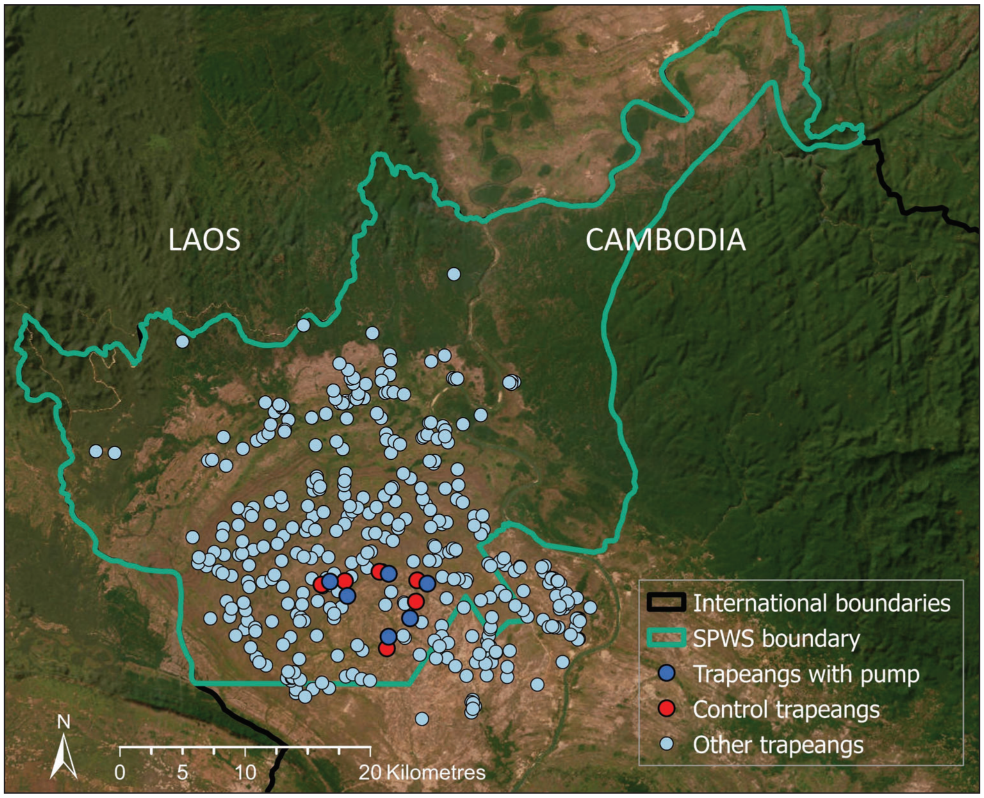

Fig. 1 Distribution of known trapeangs and trapeangs with camera traps deployed in deciduous dipterocarp forest in Siem Pang Wildlife Sanctuary. Two camera traps were deployed at each trapeang.

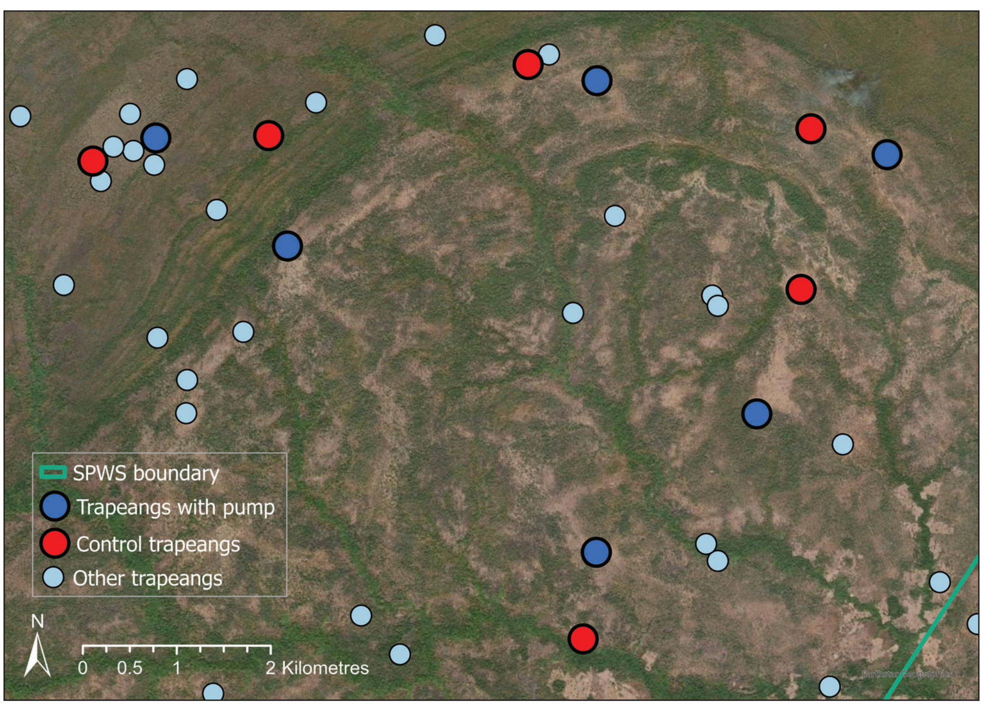

Fig. 2 Indepth view of study trapeangs and other trapeangs not monitored. Darker green shading represents semi-evergreen forest.

controls). Two cameras were deployed at each trapeangs and were placed to maximise coverage of the area and increase detection of visiting wildlife, providing a total of 24 cameras deployed in 2021 and 22 in 2022. Each trapeang was considered as a single station in our study design, although camera images were treated separately in analysis. Camera placement at each site was determined by signs of wildlife activity such as tracks around the waterhole, optimal placement for passive infrared sensor detection, or based on expert opinion and advice from field staff as to the best location. The proximity of dirt roads, direction of the sun, location of an appropriate tree to mount the camera and nearby vegetation were also considered in placement. As Eld's deer were the study target, cameras were attached ca. 0.8m above ground level to appropriately positioned trees close to the edges of trapeangs. Vegetation that might obstruct the field of view was removed. Cameras were set to take photographs at set time intervals and when motion was detected. A time-lapse plus mode was employed to take a picture every 60 minutes. Rapid-fire mode was enabled, resulting in eight photos per detection with a one second delay between triggers. Sensitivity was set to high and flash to long range (detection & flash range up to 25 m).

Cameras were deployed in the field from 9 December 2020 to 10 June 2021 and from 1 February to 15 May 2022. This corresponded to 366 camera-trap-nights per station in 2020–2021 and 206 camera-trap-nights per station in 2022, both coinciding with the dry season.

Image analysis

A total of 67,346 images were obtained for 2020–2021, and 36,871 for 2022 (totalling 104,217 images). Images were uploaded on Wildlife Insights (<www.wildlifeinsights.org/>) for species identification. Wildlife Insights is an online platform that provides tools for users to upload, manage, and analyse camera trap data, as well as share it with other researchers and conservationists. The platform uses artificial intelligence and machine learning algorithms to identify species in camera trap images, helping researchers to analyse their data. Images were automatically grouped and treated in sequences of 60 seconds. Images taken less than 60 seconds apart were considered as belonging to the same sequence, resulting in the segregation of 14,592 different sequences. All sequences were visually checked by one reviewer and tagged as blank or identified to species level where possible.

Data analysis

Data exported from Wildlife Insights were analysed using R 4.2.2 (R core team, 2022) with the camtrapR package (Niedballa *et al*., 2016). In line with previous research on Eld's deer in SPWS, we defined independent events as sequences of the same species at the same station separated by six minutes or more (Ladd, 2022). Patterns of activity (i.e., how animals distribute their activity throughout the 24 h day) were determined by plotting a kernel density estimation of activity based on timestamps for each independent event in 2020–2021 and 2022. To compare the number of sequences recorded for each of the two groups of trapeangs, we used Mann-Whitney tests to compare numbers of sequences recorded for each of the two groups of trapeangs each year as well as the entire study period. We also compared data for the two groups from March and April in 2021 and 2022, as water is minimal during these months and so differences in visitation between the two groups could be greatest until the first rains arrive (usually at the end of April).

Rainfall data

Empirical data on rainfall are not recorded using rain gauges or other devices in the Siem Pang area and the closest meteorological station is located some 80 km away in Stung Treng Province (Smith, 2023). However, retrospective datasets are available through NASA's global modelling and assimilation office tool MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, Vers. 2). MERRA-2 provides a long-term global reanalysis of the atmosphere (from 1980 onwards), incorporating space-based observations into its atmospheric general circulation model to generate estimates of rainfall on a particular land surface, with a monthly resolution.

Results

Our six treatment trapeangs were served with pumps that maintained water levels throughout the dry season, whereas our six control trapeangs were left to dry out naturally. Only one of the latter retained some water throughout the dry season in 2021, whereas all but one retained some water through the 2022 dry season (when rain occurred). Our total effective sampling effort was 3,690 camera-trap-nights in 2020–2021 (representing 84% of the total potential effort) and 1,731 camera-trap-nights in 2022 (76.4% of total potential effort). The difference is attributable to vandalism (i.e., memory cards stolen or cameras turned off) or cameras running out of battery power during the sampling period.

A total of 14,592 60-second data sequences were recorded and tagged in Wildlife Insights, of which 7,580 were blank (51.9%), 1,385 recorded Burmese hare *Lepus*

Table 2 Eld's deer detections at study trapeangs using a six-minute independence threshold. Only one camera trap was active at trapeang Thmor in 2021 and no camera was set there in 2022.

Supplemented Trapeang (2021)	#	**Control Trapeang (2021)**	#	**Supplemented Trapeang (2022)**	#	**Control Trapeang (2022)**	#
Angkrong	0	Thmor	0	Angkrong	4	Thmor	N/A
Kdoeung	92	Umpiel	132	Kdoeung	192	Umpiel	5
Khmun	36	Khtum	41	Khmun	3	Khtum	7
Lumporn	7	Trakoun	13	Lumporn	20	Trakoun	9
Lumtier	8	Thmat Kon	17	Lumtier	5	Thmat Kon	1
Thmea	50	Kontout	24	Thmea	93	Kontout	14
	193		**227**		**317**		**36**

peguensis (9.5%), 1,208 recorded domestic water buffalo (8.3%), 932 recorded Eld's deer (6.4%), 858 recorded humans (staff & villagers) (5.9%), 800 recorded northern red muntjac (5.5%), 448 recorded domestic cattle (3.1%), and 445 recorded wild pig (3.1%).

When the data were considered in terms of independent events, Eld's deer were detected in 773 out of a total of 5,939 independent events for all species (compared to 661 events provided using a 30-minute threshold). Eld's deer were detected at ten of 12 stations in 2020–2021, for a total of 420 events, with between 0 and 132 events per station ($\bar{x}$=35, SD=40.2 events per station). In 2022, the species was detected at all 11 stations, for a total of 353 events, with between 1 and 192 events per station ($\bar{x}$=32.1, SD=59.1 events per station) (Table 2).

Of the 773 independent events obtained for Eld's deer, we counted 1,387 Eld's deer, with a mean group size of 1.8 (SD=1.2, with 1–10 animals simultaneously counted). Eld's deer occurred in groups of two or more in 326 events (42.2%), with a mean group size of 2.9 (SD=1.2). Males were evident in 310 events (40.1%) and were recorded alone in 239 of these (77.1%). Detections of males increased over the course of the dry season and peaked in March. They were present in groups in 9% of images in January (2/22), but in more than a quarter of images for February (15/63), March (39/165) and April (15/57) (Fig. 3).

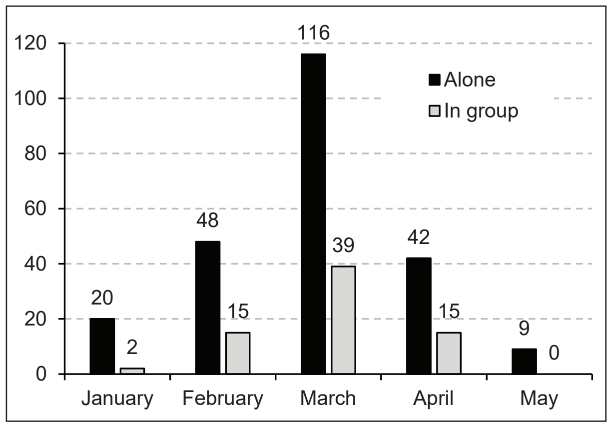

Fig. 3 Detection of male Eld's deer as solitary animals and in groups. Detections increased over the dry season and peaked in March.

Combining both study years, 510 sequences of Eld's deer were recorded at supplemented trapeangs (with pumps) whereas 263 sequences were recorded at control trapeangs. However, no significant difference was found between the two groups (number of sequences at supplemented vs. control trapeangs) using a Mann-Whitney test (U=59.5, p=0.36). The same was found when detections were segregated by year (2021: U= 16.5, p=0.44; 2022: U= 11.5, p=0.29) and month (number of independent events recorded in March or April of each year) (March 2021: U=17.0, p=0.47; April 2021: U=10.5, p=0.13; March 2022: U=9.5, p=0.10; April 2022: U=10.5, p=0.13). Given the small size of our two groups however, no definitive conclusion can be drawn from the absence of statistically significant differences.

The mean duration of the 773 independent events was 34.1 seconds from the first to the last image (range 1–464, SD=54.5 seconds). When adult males were alone in sequences (n=239), their mean duration was 15.9 seconds (range 1–275, SD=26.4 seconds).

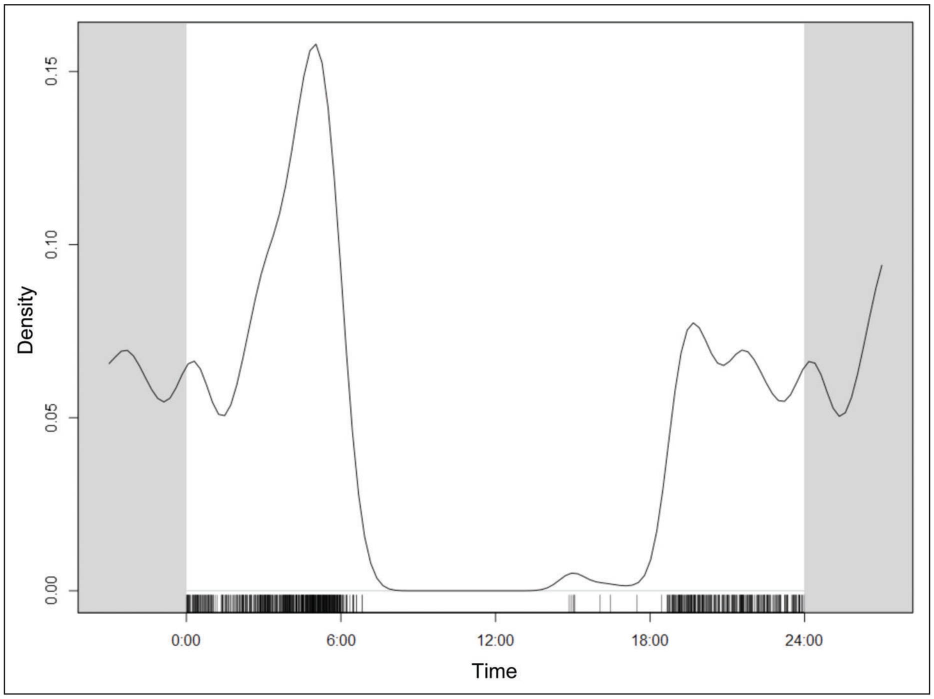

Fig. 4 Kernel density estimates of activity of Eld's deer, based on camera trap records (*n*=773) at 12 study trapeangs in Siem Pang Wildlife Sanctuary, 2021 and 2022.

Fig. 5 Two male Eld's deer bathing in late afternoon at a trapeang in Siem Pang Wildlife Sanctuary.

Activity patterns

Eld's deer visits to trapeangs were mainly nocturnal, with most activity occurring between 1900 and 0600 hrs and a peak of activity between 0400 and 0600 hrs (Fig. 4). It was not possible to identify the behaviour of animals in most images, aside from walking/standing still and head up/down, although some animals were infrequently seen bathing, fighting or drinking (Fig. 5).

Discussion

Numbers of detections of Eld's deer varied greatly between trapeangs and years. For example, in the supplemented trapeang group, 192 events were recorded at Kdoeung station but only three at Khmun during the same 2022 survey. Likewise, at Umpiel station (control), 132 events were recorded in 2021 but only five in 2022. Additionally, large differences were observed between the first and second survey years, beyond those of individual trapeangs. In the second survey year, four of the five trapeang pairs showed higher use of supplemented trapeangs, versus only one out of six in the first year. Two trapeang pairs especially displayed large differences (Kdoeung/Umpiel & Thmea/Kontout). Factors underlying these differences are likely diverse and probably include variations in meteorological conditions as well as ecological factors.

The 2020–2023 period was a rare triple-dip La Niña event (NASA Earth Observatory, 2022) and regular rainfall occurred throughout the dry season in Cambodia. According to the MERRA-2 model, an unusual amount of rain occurred in February 2021 and January–March 2022 period (Table 3). This above average rainfall may have resulted in Eld's deer visiting these trapeangs less than compared to more typical, drier years, as water would have been more available throughout the DDF. This variability in rainfall, combined with the lack of baseline data on trapeang use before our study, makes it difficult to discern possible associations between water manipulation and trapeang use by Eld's deer. A major caveat of our study is that we were not able to reliably record changes in water availability at trapeangs or local rainfall during the study period. As a result, we cannot look for correlations between these variables and monthly detection rates of Eld's deer. Marker pegs were deployed to monitor changes in water levels during the first study year, but these were found to be ineffective due to wallowing buffalo and subsequently removed. Variability between years at the same trapeang could also be due to other factors such as increased disturbance or illegal hunting pressure, whereas variability between stations could be due to shifts in the occupancy and density of Eld's deer within the sanctuary, though no data are available to confirm this theory. Many factors could be at play, such as differences in the habitats surrounding trapeangs (e.g., open grassland vs. trees at a higher density), plant species richness, water quality or occupation of the trapeangs by water buffalo.

Several other factors linked to the study design may also have influenced the detectability of Eld's deer. For instance, we selected camera traps with infrared flash over white flash due to time and budget constraints. This makes individual identification of large animals less efficient and can impact the ability of a reviewer to identify species, in our case to differentiate between Eld's deer and northern red muntjac (Meek *et al*., 2014; Ladd *et al*., 2022c). The images produced by the cameras were also substandard in daylight hours and blurring made identification difficult at times. Despite having two cameras at each station, the field of view and detection zone did not always fully cover all edges of trapeangs and so could have under-detected visits by Eld's deer. Another caveat lies in the difficulty of finding statistical differences between the treatment and groups. Only six trapeangs were deepened and equipped with solar pumps, a rather low sample size that would necessitate a high number of Eld's deer detections to provide clear results. We did however observe an increase in visitation at supplemented trapeangs.

Table 3 MERRA-2 precipitation corrected figures (mm) for the study area (14.1457°N, 106.2477°E).

Year	Jan	Feb	Mar	Apr	May
2020	0.0	0.0	15.8	52.7	0
2021	0.0	15.8	0.0	183.8	8.1
2022	20.7	16.3	105.5	80.9	N/A
Mean 1981-2020	2.9	5.1	17.5	48.3	6.2

More Eld's deer events were recorded in March (*n*=332, almost 43% of those recorded) than February (*n*=235) or April (*n*=104). Our survey in 2022 was shorter than in 2021 which precluded comparisons with January and May. Although the breeding cycle of *R. e. siamensis* is unclear, it likely follows the pattern observed for *R. e. thamin* in Myanmar, with mating occurring in March or April and fawns born in November–December (Aung *et al*., 2001). Because Eld's deer increase their activity during the rut period, this could lead to an increase in detections and indeed our detections were significantly higher in February, March and April. Changes in detection likely also reflect season and water availability, with animals concentrating at fewer trapeangs as these dry out and wider water availability reduces within the sanctuary. In 2021, the first rains in SPWS occurred at the end of April when most of the control trapeangs had dried out, whereas scattered rain occurred during the dry season in 2022 and most trapeangs retained some water. Additionally, rains are not evenly distributed across the landscape and some trapeangs may benefit from earlier rain than others.

While this could explain our increased detections in March, our results differ from Ladd (2022) who reported higher detections in SPWS in May (which corresponds to the early rainy season) and lower detections in March during the rut and dry season when the landscape has dried out (Ladd, 2022). However, it is important to note that we deployed camera traps at trapeangs whereas Ladd (2022) deployed camera trap arrays throughout the dry forest. It is likely that our higher detections in March are related to the extreme scarcity of water in the DDF.

Previous studies have described the social organization and group size of *R. e. thamin* in Myanmar during the hot dry season. Our mean group size of 1.8±1.2 found in our study is much smaller than that found in Shwesettaw Wildlife Sanctuary in Myanmar where mean group size was 7.6±0.9 (Thu *et al*., 2019) and in Chatthin Wildlife Sanctuary where this peaked in April at 5.9±8.3 individuals (Aung *et al*., 2001). The maximum number of individuals we recorded simultaneously was ten, which is consistent with group sizes usually spotted in SPWS, although groups of up to 29 individuals have also been recorded simultaneously (Rising Phoenix, unpubl. data). Groups of up to 28 and more than 70 individuals were described by Thu *et al*. (2019) and Aung *et al*. (2001) respectively. These differences could be due to a lower population density in SPWS, as a positive relationship has been identified between group size and population density has been documented in other cervids, or by the fact that according to Thu *et al*. (2019), large groups of Eld's deer in Shwesettaw Wildlife Sanctuary avoid areas near water sources as predation and hunting pressure are higher. Eld's deer visitations at trapeangs were mainly nocturnal in our study, which may be a predator avoidance behaviour triggered by human disturbance, as observed in Hainan (Pan *et al*., 2011).

In camera traps studies, time-to-independence intervals of 30 to 60 minutes are frequently used, whereby all images of the same species are filtered and discarded within this interval for each camera (Peral *et al*., 2022). However, the interval setting is largely arbitrary and is probably species dependent. For example, Ladd (2022) used the lorelogram technique of Iannarilli *et al.* (2019) on a set of data for Eld's deer to empirically determined an independence interval of six minutes for the species. We adopted this treatment in our study. The definition of Ladd (2022) for independent events was based on an analysis of detections from 40 camera traps deployed in the dry forest which provided 368 detections of Eld's deer over 4,026 camera trap nights between December 2018 and May 2019. In addition to being arbitrary, choosing a longer interval usually results in loss of data, which is problematic for studying species that occur at low density and are difficult to detect. In our case, a 30-minute threshold would have reduced the number of independent events by roughly 15% but would not have changed our data analysis and interpretation unduly.

Finally, reviewing and tagging camera trap images is a time-consuming process. Use of the Wildlife Insights platform proved to be effective in removing barriers related to image cataloguing and data storage that are often associated with large datasets such as the >100,000 images in our study (Glover-Kapfer *et al*., 2019; Ahumada *et al*., 2020). Though artificial intelligence was ineffective most of the time in recognizing animals to the species level (and the class and family level to some extent), it was helpful in grouping the images by sequences for review, identifying blank images with adequate accuracy and common species such as dogs or cattle. Recognition of humans or vehicles in the images was also very good.

Conclusions

Siem Pang Wildlife Sanctuary is one of the last strongholds for Eld's deer in Cambodia, but the population is threatened by human activities and climate change which risks changes to rainfall patterns and longer and harsher droughts and ecosystem modifications. To mitigate these threats, we modified several trapeangs by deepening these and installing solar-powered water pumps. We designed our camera-trap study to compare visits of Eld's deer between supplemented and control trapeangs over the course of the dry season. However, we did not find a significant difference due to a small sample size and high variability between years and within groups. This was likely due to factors including variations in rainfall locally and between years, as well as ecological factors and Eld's deer behaviour, but given the design of our survey, it was not possible to resolve the multiple hypotheses. Future studies of trapeang use need to occur over a longer temporal scale to account for variation in rainfall and subsequent trapeang use by wildlife. Our study could be improved on by expanding sample size, monitoring local rainfall using rain gauges and employing water gauges to objectively record water levels at trapeangs. Nevertheless, our results provide a baseline for future studies of trapeang use by Eld's deer trapeang in SPWS and will aid future decision-making in management of trapeangs.

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