Abstract: Eld’s deer (Rucervus eldi) was once widely distributed across Southeast Asia, however the species is now listed as Endangered, having suffered severe population declines and range contractions. Cambodia has been considered a strong hold for the Eld’s deer subspecies R. e. siamensis, however there is limited population data available for this species within Cambodia, making its status unclear. Here, we collated all records of Eld’s deer presence between 2000 and 2020 to provide an insight into the current status of the species in Cambodia. Data was sourced through literature review as well as the internal databases of conservation organisations and biodiversity surveys. Our findings reveal that very small, spatially isolated populations of Eld’s deer are now largely restricted to nine areas in the eastern and northern parts of the country and that urgent conservation action is required to secure the future of this species in Cambodia. Effective law enforcement and anti-hunting strategies, implementation of management plans within protected areas as well as investigation into the potential of captive populations to support the conservation of Eld’s deer in the wild are essential for preserving this species.

Keywords: Cambodia; conservation status; Eld’s deer; Rucervus eldi siamensis.

1 Introduction

Southeast Asia is a global biodiversity hotspot and, unfortunately, it is also a hotspot for human impact on biodiversity (Allan et al. 2019). This region currently experiences the highest rate of deforestation among tropical regions (Austin et al. 2017; Sodhi et al. 2010) and almost all remaining forests are subjected to differing levels of illegal hunting (Corlett 2007; Harrison 2011; Harrison et al. 2016). It is therefore unsurprising that large-bodied mammals in Southeast Asia have lost more than 80% of their geographic ranges, and have undergone significant population losses (Ceballos et al. 2017). Overexploitation of remaining populations for human consumption is the most significant threat to megafauna, and will inevitably result in further population declines and species extirpations (Ripple et al. 2019).

In Cambodia, the combination of deforestation and the killing of wildlife for consumptive and non-consumptive purposes has already resulted in the presumed extinctions of several large-bodied vertebrates, such as the kouprey (Bos sauveli) and Indochinese tiger (Panthera tigris corbetti) (O’Kelly et al. 2012; Timmins et al. 2016). Whilst sufficient levels of forest cover still exist, local extirpations, population declines and range contractions of several medium to large-bodied herbivores including gaur (Bos gaurus), banteng (Bos javanicus), sambar (Rusa unicolor) and the globally Endangered Eld’s deer (Rucervus eldi) will likely continue to occur due to the ongoing demand for wildlife meat and products (Griffin and Nuttall 2020; Groenenberg et al. 2020).

Eld’s deer is a large tropical cervid that historically occurred across Southeast Asian deciduous dipterocarp forests (DDF), from the Manipur region of India, through Myanmar, Thailand, Cambodia, Lao PDR, Vietnam and into southern China and Hainan Island (Gray et al. 2015a). However, this species has suffered significant declines throughout its former range, now only occurring in small, spatially isolated populations, and as a consequence was listed as globally Endangered in 2008 (Gray et al. 2015a).
There are three officially recognised, geographically distinct subspecies: *R. e. eldii* occurs in a very small population in India, *R. e. thamin* ranged across Myanmar and westernmost Thailand, and *R. e. siamensis* was distributed across Cambodia, Lao PDR, Vietnam, Thailand and Hainan Island (Gray et al. 2015a). Eld’s deer is now considered extirpated in Vietnam and Thailand, however Thailand has commenced reintroductions with *R. e. thamin* (Gray et al. 2015a). The current status of *R. e. eldii* and *R. e. thamin* are detailed in Singh and Khare (2018) and McShea et al. (2018) respectively. In contrast, the current status and distribution of *R. e. siamensis* is less clear. The Eld’s deer population on Hainan is often referred to as a fourth subspecies, *R. e. hainanus* (Zeng et al. 2005). Results from a genetic study by Balakrishnan et al. (2003) indicated that the mtDNA haplotype is unique for this islandic population, however they did not support the distinction of a separate subspecies, thus it is still classified as *R. e. siamensis* on the IUCN Red List (Gray et al. 2015a). However, an ongoing genomic study may yet confirm the distinctiveness of the Hainan population, with preliminary results suggesting genetic distinction (Wong et al. 2021). Whilst the debate over the genetic distinctiveness of the Hainan population is unresolved, it is the most studied population (Wong et al. 2021). The Hainan population consists of 700–800 individuals primarily considered to exist in a semi-wild capacity (Wong et al. 2018) and for this reason was not considered in the Red List assessment. Gray et al. (2015a) estimated that the *R. e. siamensis* population in Cambodia had declined by 90% or more in the 2000s, with ancestral wild populations in Thailand and Vietnam likely extinct. Despite local extirpations and range contractions, robust population estimates and current spatial distribution data are largely lacking. Lao PDR has only one confirmed population and this was recently estimated to include 173 individuals (95% CI: 99–305) at Xonnabouly Eld’s Deer Sanctuary (Khotpathoom and Vu 2020). However due to the low number of observations, this estimate needs careful interpretation. The largest wild population of *R. e. siamensis* is perceived to exist in spatially fragmented populations throughout the north and east of Cambodia (Gray et al. 2015a). Consequently, Cambodia is still considered a stronghold for this species, despite limited population data.

From 1925, protected areas began to be established in Cambodia to protect cultural and biodiversity values, with approximately 12% of the country falling under some form of protected area designation by 1970 (Protected Areas and Development Partnership 2003). However, subsequent armed conflicts in Cambodia took a high toll on biodiversity due to the proliferation of firearms, presence of soldiers in forested habitats, disruption of food production systems, land-use changes and dissolution of protected areas under the Khmer Rouge, leading to significant declines in a number of species, including Eld’s deer (Loucks et al. 2009; Protected Areas and Development Partnership 2003). Protected areas began to be re-established in 1993 and Cambodia now has a relatively extensive network of protected areas (Protected Areas and Development Partnership 2003; Souter et al. 2016). Post conflict, there has been an increased effort toward pursuing sustainable development and environmental protection goals, with approximately 40% of the country’s landmass having some sort of protected area classification (UNEP-WCMC 2020). However, the majority of protected areas are underfunded and lack long-term sustainable levels of investment. As a result, many of these areas are understaffed and resourced, with only basic infrastructure in place. A further challenge is that the majority of protected areas lack boundary demarcation and management and zoning plans (Ministry of Environment 2017). Thus, despite Cambodia’s efforts to conserve large tracts of forested areas, it had the fifth highest percentage loss of forest cover globally between 2000 and 2012 (Hansen et al. 2013). A proportion of forest loss appeared to be linked to the widespread granting of Economic Land Concessions (ELCs) for agricultural intensification purposes, including land located within protected area boundaries. Forest loss has been shown to be much higher within ELCs (Davis et al. 2015), with evidence suggesting timber extraction has taken higher priority than converting land for agricultural purposes in some cases (Beauchamp et al. 2018).

In 2005, large areas of suitable habitat for Eld’s deer were identified from habitat modelling in Cambodia (McShea et al. 2005). Despite the rate of forest loss since this study, substantial areas of appropriate habitat within protected areas still remains. Whilst the total area of protected forest across Cambodia has increased over recent decades, species extirpations and population declines are still occurring and illegal hunting remains the most significant and immediate threat to terrestrial wildlife in Cambodia (Harrison 2011; Harrison et al. 2016). This also appears to be the case for Eld’s deer, as suitable areas with sufficient habitat coverage to support viable populations were found to be either devoid of Eld’s deer or supporting only small fragmented populations (McShea et al. 2005; O’Kelly et al. 2012).

Hunting pressures across Southeast Asia, including Cambodia, have increased over recent decades due to human population growth, increased national and international demands for products, as well as improvement in infrastructure projects which subsequently increases
levels of accessibility to forested areas and trade routes to suppliers (Corlett 2007; Harrison et al. 2016; Hughes 2017). Whilst limited published data exist in Cambodia, and hunting prevalence is challenging to determine with certainty, recent studies indicate that prevalence likely varies between locations with it being a relatively common activity of rural households in Cambodia: 83% of households across three villages in the Cardamom Mountains reported having hunted in the past year (Coad et al. 2019). In contrast, only 9% of households in 18 villages within Keo Seima Wildlife Sanctuary reported hunting, although 33% of households reported catching wild animals to eat (Ibbett et al. 2020). Significant majorities of Cambodians living in rural villages have a preference for eating wild meat, while there is also high demand from growing urban middle class consumers (Belecky and Gray 2020; Coad et al. 2019; Ibbett et al. 2020). External professional hunters target large and/or high value animals for commercial trade (Wutty and Simms 2005), however there is limited recent information available on such trade in Cambodia. As Eld’s deer is now a rare animal, it is likely only taken opportunistically, and they are vulnerable to snaring.

Various techniques are used to illegally hunt mammals; however, the widespread use of snares is considered particular cause for concern, due to the ability to capture, injure and kill a range of different size mammals (Gray et al. 2017). It is also difficult to prevent: snare materials are cheap, widely available and once deployed are difficult to detect for removal (Gray et al. 2017; O’Kelly et al. 2018). There is an estimated 12.3 million snares present in the protected areas of Cambodia, Lao PDR and Vietnam (Belecky and Gray 2020) and there has been a notable increase in lethal traps in at least two protected areas over the last decade in Cambodia (Groenenberg et al. 2020). In addition, Eld’s deer are also considered relatively easy to hunt compared to other sympatric deer, due to their preference for open habitats and a behavioural tendency to freeze in the presence of a perceived predator (Gray et al. 2015a). Hunting with dogs is the most commonly reported hunting method in Keo Seima and very common in the Northern Cardamom Mountains (Coad et al. 2019; Ibbett et al. 2020), while hunting with firearms is also a serious concern, with law enforcement confiscating 20 home-made guns in the Eastern Plains Landscape in 2017 alone (WWF-Cambodia 2017). Even when people are not hunting, dogs often accompany people on forest visits, and the dogs pose a threat to wildlife, with fawns particularly vulnerable (Gray et al. 2015a; Ibbett et al. 2020).

Although Cambodia supports significant populations of globally threatened vertebrates, biodiversity data are limited to only a few protected areas and historical data are scarce. One of the earliest records of large herbivore presence stems from an ecological survey in the north and east of Cambodia, which states that Eld’s deer were relatively common in these areas (The Wild Cattle of Cambodia 1957; Wharton 1957). However, just over 10 years later, Eld’s deer were described as approaching critical minimum (Wharton 1966). Despite the current Endangered listing and the apparent rate of decline of Eld’s deer in Cambodia, population estimates and current estimated distribution is primarily limited to expert opinion and ad hoc data collated from some site-specific biodiversity datasets. Furthermore, this lack of robust data and limited information hinders the ability to scientifically publish information on Eld’s deer. Subsequently, abundance and spatial distribution data and information for this species is generally restricted to internal databases, unpublished documents and reports of limited circulation and accessibility. This paper aims to compile all available records for Eld’s deer to gain a greater understanding of its current status in Cambodia. We also identify the most pressing priorities for the management of this species.

2 Study area

Cambodia is located in Southeast Asia, and borders Thailand, Lao PDR and Vietnam. It is characterised by a low lying central plain, surrounded by uplands and low mountains, and experiences two distinct seasons: the monsoon season from May to October and the dry season between November and April. As of 2020, there are 76 natural protected areas listed under eight different classification systems, with 75 terrestrial sites, including natural heritage sites, national parks and multi-use management areas, shown in Figure 1 (Open Development Cambodia 2020). There have been several name changes to some protected areas, so we have endeavoured to use the current names wherever possible. While we did not actively exclude any areas of Cambodia from our study, due to the scarcity of data available in the public domain, records were predominantly obtained from protected areas with non-governmental organisation (NGO) presence, where variable levels of wildlife research and monitoring are typically conducted. The majority of these areas are officially classified as Wildlife Sanctuaries or National Parks. Furthermore, the remaining DDF habitat favoured by Eld’s deer is most commonly found in the north and east of the country, with some additional patches to the west and south (McShea et al. 2005).
3 Methods

We searched for Eld’s deer data and records from the last two decades and divided them into the following three source categories: literature; incidental records stored within internal databases; and records from biodiversity surveys. This last category includes information obtained from an array of biodiversity surveys, which vary from longitudinal multi-species ungulate and predator surveys, to single species surveys. Monitoring activities specifically for Eld’s deer and other ungulate species regularly occur in five protected areas. However, the results of the Eld’s deer targeted surveys have not previously been published due to methodological constraints and low detections. Multi-species line transect survey results conducted in Keo Seima, Phnom Prich and Srepok Wildlife Sanctuaries have previously been published, but as Eld’s deer detections were severely limited, these results were either not reported or reported in limited detail (Gray et al. 2012; Grifflin and Nuttall 2020; Groenenberg et al. 2020; Nuttall et al. 2013; Rostro-Garcia et al. 2018). Furthermore, the methodology has changed at each of these sites since monitoring began. Therefore, the details of the methods and results of these line transect surveys, as pertaining to Eld’s deer, are also reported here. For camera trap surveys, we provide only the basic details due to the high level of variation in methods implemented across sites and focal species. All Eld’s deer records were grouped by date, with records between 2015 and 2020 considered recent, indicating the continued existence of a population, while records between 2000 and 2014 were considered old, with the current status of Eld’s deer at these sites unknown and possibly lost. Any records prior to 2000 were considered historic, with Eld’s deer at these sites unlikely to still be present.

3.1 Literature review

A search was conducted for any Eld’s deer records in peer reviewed journal articles, non-governmental and governmental reports and dissertations published between the years 2000 and 2020. The literature search was conducted initially in January 2020 and again in February 2021 using Web of Science and Google Scholar. The search terms “Rucervus eldi + Cambodia”, “Eld’s deer + Cambodia”, “Cervus eldi + Cambodia” and “brow-antlered deer + Cambodia” were used. Duplicate papers were removed and the results were sorted manually to discard all papers that did not feature data from Cambodia and that did not include the siamensis subspecies. Other papers were excluded based on the abstract, for example if the contents entirely focused on husbandry, veterinary science, culture, tourism or genetic studies not

![Figure 1: Map of protected areas in Cambodia.](image)
based on field samples. The remaining papers were reviewed to determine whether they contained records. Any literature that only utilised previously reported data were discarded from the results to prevent duplication.

The papers checked for Eld’s deer records were also reviewed for references that may contain additional Eld’s deer records, which were then acquired where possible. Additional unpublished or limited circulation reports were obtained by contacting national and international conservation NGOs based in Cambodia. The same criteria above were applied for all additional literature gathered.

3.2 Incidental records

Several NGOs and other organisations working in protected areas or areas of biodiversity significance keep databases of incidental records of notable species sightings and their signs. The Spatial Monitoring and Reporting Tool (SMART <https://smartconservationtools.org/>) is becoming more frequently used across a number of protected areas in Cambodia. This management tool was developed by a number of conservation organisation partners to effectively gather and consolidate data from field patrols and other activities. Secondary sightings of notable wildlife are also often made during survey work unrelated to ungulates, or when they occur outside of the survey scope, and are also recorded within SMART or other biodiversity databases. We requested that SMART databases, as well as other internal databases and reporting systems, from BirdLife International Cambodia Programme, Wildlife Conservation Society Cambodia Program (WCS), World Wide Fund for Nature Cambodia (WWF), Rising Phoenix Co. Ltd., Conservation International, Flora and Fauna International, Wildlife Alliance, the Fishing Cat Project and BeTreed Adventures be searched for all Eld’s deer records for inclusion in this review. Some historical datasets, generally prior to 2010, had some missing information in the records, and did not always specify whether records were direct or indirect. All records were verified and checked for duplication, with any records lacking sufficient information to classify as independent considered unreliable or potential duplicates and were excluded. We additionally included the samples of a faecal DNA survey in Srepor and Phnom Prich Wildlife Sanctuaries in this compilation of incidental records, as data analysis is underway with results pending (draft manuscript being produced by R. Crouthers et al.). This survey was conducted in the dry season of 2017 and searches were centred on waterholes.

3.3 Biodiversity survey methods

3.3.1 Census: Ang Trapeang Thmor Protected Landscape: Eld’s deer are monitored monthly between January and April at Ang Trapeang Thmor Protected Landscape (ATT), which is sufficiently small (126.5 km²) to permit a census of Eld’s deer. These data are recorded during waterbird monitoring activities conducted by the Provincial Department of Environment rangers and community members, who have been trained in identification of Eld’s deer by WCS technical staff. Teams traverse the area on foot and by motorbikes with the specific route taken on any given day dependent on water level, field conditions and local reports on where deer have been spotted. They record all Eld’s deer seen, and note age and sex of individuals. The maximum monthly count recorded per year is used as a minimum population count estimate.

3.3.2 Rapid vehicle survey: Siem Pang Wildlife Sanctuary: Since 2015, an annual vehicle survey for Eld’s deer is conducted in April at Siem Pang Wildlife Sanctuary. Observers drive slowly in a 4 × 4 vehicle along dirt tracks through DDF habitat in the morning and/or late afternoon. The sampling effort varies between years, with slight differences in routes taken, area covered and survey duration. For every Eld’s deer sighting, GPS coordinates, time, and group configuration are recorded and photographs of each individual are taken when possible. Each individual observed is categorised as being a fawn, juvenile, small female, large female, small male with prongs, orange male with small rack, brown male with small or medium rack, or as a large brown male with large rack.

The total number of sightings made per survey day is calculated, along with the total number of different individual animals observed daily to provide a minimum population count. The uniqueness of individuals is determined by individual features such as antlers, as well as group composition. All repeat sightings are recorded, but not included within the minimum count, and it is assumed that there is no mixing between groups during the survey period.

3.3.3 Distance sampling line transect surveys: Keo Seima, Phnom Prich and Srepolk Wildlife Sanctuaries: Currently, distance line transect surveys are regularly conducted across three adjacent wildlife sanctuaries in the Eastern Plains Landscape: Keo Seima, Phnom Prich and Srepolk Wildlife Sanctuaries. The surveys target ungulates, pinnipeds and green peafowl. Certain subsets of this monitoring data have been included in several publications previously, including five publications within the literature review of this article (see Supplementary Material). However, as the reporting on method details, time periods, sites and results pertaining to Eld’s deer has varied, we are including the method and all Eld’s deer results here to provide a complete picture.

The development of the monitoring, using distance sampling methodology following Buckland (2001), began in Keo Seima in 2005. Between 2005 and 2008, the area surveyed did not include the area known to be occupied by Eld’s deer (O’Kelly and Hor 2010). The initial random stratified survey design was modified in 2010 to a systematic design with square transects that included the areas occupied by Eld’s deer. Also, in 2010, distance-based line transects commenced in Srepolk and Phnom Prich to establish population estimates and density trends (Gray et al. 2012). Since 2014, distance-based transect surveys have been conducted every two years throughout the dry season at each of the three sites. Observers walk transects in the early morning and late afternoon. In Phnom Prich and Srepolk, all transects were surveyed for a minimum of four occasions since 2014, while in Keo Seima all transects were surveyed for a minimum of two occasions. The specific details for the three sites and modifications are detailed in Supplementary Material.

3.3.4 Camera trapping: In collaboration with the Royal Government of Cambodia (RGC), WWF have conducted a number of camera trap surveys across Srepolk and Phnom Prich since the mid 2000s, and since 2013 onwards WildCru and Panthera have collaborated with WWF and the RGC in conducting several camera trap surveys to estimate large predator presence and densities. Camera trap surveys have also been conducted by WWF in Sambor Wildlife Sanctuary. Survey area, study design, trap array and duration have varied across the years depending upon the focus of the camera trap study. None of these surveys focused on obtaining Eld’s deer distribution. The results
of these studies were checked for incidental detections of Eld’s deer, however due to the survey designs and camera trap placement locations in these studies, this information is not reliable in determining Eld’s deer presence/absence or distribution. Additionally, three camera trap surveys have previously been published, and were included in the literature review section, but have also had their Eld’s deer detections included here for completeness (Gray et al. 2015a; Pin et al. 2018; Suzuki et al. 2017).

Since 2017, camera trap surveys have also been carried out in Siem Pang, with the University of Queensland collaborating alongside BirdLife International Cambodia Programme. The work included in this paper consists of pilot and exploratory camera trap surveys in which Eld’s deer was the target species, with the survey area, design and duration varying between surveys. While this is an ongoing project, the number of independent Eld’s deer detections are reported here to provide additional records for this site. Camera trap surveys have also been carried out at Chhep Wildlife Sanctuary by WCS between 2000 and 2008 for various purposes and we have included the surveys in which Eld’s deer were captured here. Key methodological details of all studies that had at least one deer detection are given in the Supplementary Material.

4 Results

The geographical distribution of all records from all sources, divided into three regions (eastern, northern, and central-western Cambodia), are depicted in Figure 2, with record details given in the following sections. We have used management area boundaries, primarily protected areas but also districts and communes, to show the location of records to provide context, without depicting exact locations. Therefore, this should not be interpreted as Eld’s deer being present throughout the indicated management areas, but as a localised subpopulation within the management area. The historical data of occurrence recorded prior to 2000 is far from comprehensive, as this was outside of the study scope, therefore, this only includes sites mentioned within the reviewed literature as having occurred there at some point prior to 2000.

4.1 Literature

The literature search resulted in a total of 320 results (duplicates excluded). After irrelevant papers were excised, 35 results remained and were checked for Eld’s deer records. A further nine documents were found after the reference lists of relevant papers were reviewed, and an additional 12 documents were supplied by NGOs, which were all checked for Eld’s deer records. A total of 30 publications (eight peer reviewed, 19 NGO/Government reports and three Master’s dissertations) included Eld’s deer records, and a detailed list of these publications is provided in Supplementary Material. Table 1 lists the published records according to location, along with the years in which records occurred and the total number of publications that contain records for the location. The majority of records featured in the literature were made prior to 2016. Five documents include confirmed records of Eld’s deer between 2017 and 2020 at six sites, three in the east (Phnom Prich, Srepok and Keo Seima) and three in the north (ATT, Seim Pang and Chhep) and an additional report includes a possible record of Eld’s deer tracks in Sambor Wildlife Sanctuary in 2018, also in eastern Cambodia. Records of Eld’s deer were primarily from broad biodiversity surveys or multi-species surveys. Only the three Master’s dissertations and a workshop report specifically focused on Eld’s deer (Ball 2017; Owen 2009; Weiler 2003; Wilkes 2017). Population estimates were only attempted within the workshop report, based on limited data and expert opinion, and a dissertation, using camera trap data (Ball 2017; Weiler 2003). The types of records vary and include indirect records such as tracks, scats, hunting trophies and interview responses, as well as direct sightings during surveys and camera trap images. Evidence of Eld’s deer presence was generally limited, often with only a few sightings, camera trap photos or tracks recorded in any given survey. Results also include records where tracks or other signs were attributed to Eld’s deer, but with some uncertainty, or where evidence was anecdotal.

4.2 Incidental records

Incidental records of Eld’s deer were only reported by BirdLife, WCS and WWF. SMART data describes recorded encounters made during various activities such as enforcement patrols and conservation work, and thus has limited reliability in indicating biodiversity presence at some sites. SMART data includes direct sightings as well as the recording of tracks and scats, which are usually distinguished in the databases. Records of Eld’s deer using the SMART system or historic reporting methods are rare in most locations, with sightings made in only a few years or with a very low frequency of annual sightings, as detailed in Table 2. In northern Cambodia, sightings were recorded most frequently in Siem Pang, with regular sightings also recorded at ATT, while at Chhep there was at least one sighting in most years. Fewer records were made in eastern Cambodia, and they occurred most often at Phnom Prich and Srepok. During 2017 there was a higher than usual number of indirect records at Srepok which is attributed to effort spent on a targeted Eld’s deer faecal DNA survey (Table 2).
4.3 Biodiversity surveys

4.3.1 Northern Cambodia

Results for the northern region of Cambodia include the census survey at ATT and the vehicle survey at Siem Pang, as well as some camera trap survey data from Siem Pang and Chhep Wildlife Sanctuaries. Between 2012 and 2020, the Eld’s deer population at ATT has declined to an estimate of only three individuals, with a peak of 35 individuals recorded in 2014. These minimum count population estimates for each year are shown in Figure 3. The rapid vehicle survey provides a minimum count of individuals at Siem Pang, however as survey effort and conditions vary between years, it is not a reliable indicator of the population size and trend. Between 2015 and 2020, the minimum count has varied between 51 and 10 individuals and is also shown in Figure 3. Results of all camera trap surveys in which Eld’s deer were recorded are summarised in Table 3. At Siem Pang, Eld’s deer camera trap detections were notably higher than at other sites, with over 100 independent detections during each survey, which is anticipated given the surveys are targeted for Eld’s deer.
Table 1: The locations and years of Eld’s deer records that appear in the literature.

| Location                        | Number of publications | Years with records          | Record type          |
|---------------------------------|------------------------|----------------------------|----------------------|
| **Northern Cambodia**           |                        |                            |                      |
| Ang Trapeang Thmor Protected Landscape | 3                      | 2000–2003                  | Direct and indirect  |
| Siem Pang Wildlife Sanctuary    | 7                      | 2002–2018                  | Direct and indirect  |
| Kulen Promtep Wildlife Sanctuary | 1                      | 2001–2003                  | Direct and indirect  |
| Chhep Wildlife Sanctuary        | 8                      | 1999–2010, 2013, 2014, 2017| Direct and indirect  |
| Prey Preah Roka Wildlife Sanctuary | 1                      | 2003–2014                  | Direct               |
| Stung Treng Ramsar Site         | 1                      | 2005–2006                  | Indirect             |
| **Eastern Cambodia**            |                        |                            |                      |
| Srepol Wildlife Sanctuary       | 5                      | 1999–2007, 2013–2016, 2018 | Direct               |
| Snoul Wildlife Sanctuary        | 1                      | 1999–2007                  | Direct               |
| Keo Seima Wildlife Sanctuary    | 2                      | 2013, 2020                 | Direct and indirect  |
| Phnom Prich Wildlife Sanctuary  | 4                      | 1999–2007, 2009–2011, 2014, 2016, 2018 | Direct and indirect |
| Ou Ya Dav National Park         | 1                      | 2000–2006                  | Direct and indirect  |
| Sambor Wildlife Sanctuary       | 1                      | 2006, 2018                 | Indirect             |
| **Central-Western Cambodia**    |                        |                            |                      |
| Phnom Aural Wildlife Sanctuary  | 3                      | 2000–2003                  | Direct and indirect  |
| **Multiple regions**            |                        |                            |                      |
| Non-protected areas             | 3                      | 1994, 1999, 2001–2003, 2006| Direct and indirect  |

The number of publications that include records at each location is indicated, with some publications including records from multiple sites. The year records were made is included, however where a range is given, this indicates that there were insufficient details in the literature to specify the exact year, hence there are not records for every year within the range given.

detection. Eld’s deer captures were low in Chhep, with a maximum of 19 independent detections in 2004.

4.3.2 Eastern Cambodia

Results from the eastern region of Cambodia includes the distance sampling line transect surveys, as well as some camera trap survey data. Pooled or stratum specific density estimates could not be produced for Eld’s deer due to the low number of encounters on the transect surveys. Sightings of Eld’s deer were made at Keo Seima in 2013, 2016 and 2018, giving encounter rates during those years of 0.0016, 0.0024 and 0.0016 individuals per km respectively (WWF, unpublished data). At Keo Seima, all observations were made on the same transect in the same area, suggesting a limited range within the protected area. Eld’s deer sightings were also made at Phnom Prich in 2016 and 2018 and at Srepok in 2011 and 2014, giving encounter rates of 0.0019, 0.0008, 0.0096 and 0.0133 respectively (WWF, unpublished data). Transect survey result details for the three wildlife sanctuaries are reported in Table 4.

Eld’s deer were not recorded on any of the large predator camera trap surveys conducted in Phnom Prich and Srepok. However, this was not unexpected given that camera traps were placed along roads and trails in mixed habitat types. The lack of detections should not be taken as confirmation of absence as the particular priorities of survey design may not favour Eld’s deer detection. Multispecies camera trap surveys of waterholes yielded the highest number of encounters in this region, with the maximum of 71 independent detections recorded in Srepok in 2016 (Pin et al. 2018; Table 3). Detections were low in Sambor Wildlife Sanctuary with a single detection in 2015 and again in 2020.

5 Discussion

In Cambodia, Eld’s deer presence appears to be largely restricted to at least nine protected areas in the eastern and northern parts of the country, with Siem Pang and Chhep in the north and Srepok, Phnom Prich and Keo Seima in the east likely containing the largest populations. The inability to produce population estimates at three sites (Keo Seima, Phnom Prich and Srepok) using distance sampling, which has been successful for more populous species at these sites, indicates that the remaining scattered populations have been severely depressed. Much of the literature, particularly outside of the key sites of Keo Seima, Srepok and Phnom Prich in the east and Siem Pang and Ang Treadang Thmor (ATT) in the north, which are subject to regular ungulate monitoring, is relatively old and may no longer be an accurate indication of presence. Incidental record data seems to be the only recent available data on ungulates such as Eld’s deer in the northern wildlife sanctuaries of Prey Preah Roka and Kulen Promtep as well as Lomphat in the east, however the effort, area coverage and consistency of data collection is highly variable within
and across sites. SMART data collection is often generated by law enforcement patrol teams, including both foot and motorbike patrols. Thus, the key focus of their efforts is combatting and mitigating illegal activities, not recording biodiversity presence. However, this is supplemented at many sites by secondary records made during other survey and conservation work, for example during bird nest or other species surveys. Furthermore, at Siem Pang a dedicated team of biodiversity rangers include all their sightings within the same database. At this site, the increasing number of Eld’s deer records may be attributed in part to improved area coverage, training and targeted species search effort. It may also be an indicator of improved enforcement resulting in reduced hunting levels at this site. Consequently, use of this data alone cannot provide an accurate indication of distribution or population trends, thus it is not the most reliable indicator of presence for a rare species such as Eld’s deer.

The limited and variable nature of Eld’s deer records available makes it difficult to determine the exact status of the species in Cambodia, and there is potential for subpopulations to go undetected in areas with limited focused research. However, it is clear that this species is very rare, and the remaining fragmented populations across the country are only found at nine sites (confirmed records since 2015), and possibly five others (confirmed record since 2000), and they appear to be severely depressed (Figure 2). Only Chhep and ATT in northern Cambodia have recent population estimates: 75 individuals at Chhep in 2017 (Ball 2017) and three at ATT in 2020. However, the Chhep estimate is highly questionable as serious violations of analytical assumptions were made, which likely caused an inflated result and the actual population size is likely to be considerably lower. In light of this, and based on the other records presented here, it seems that Siem Pang in northern Cambodia may support the largest population, however, this is a tentative assertion given the lack of targeted survey effort in areas with Eld’s deer populations. It is also of great concern that the potentially largest population is still very small, with the largest minimum count recorded at only 51 individuals in 2015.

### Table 2: Number of incidental records at 10 sites: Ang Trapeang Thmor Protected Landscape (ATT), Chhep Wildlife Sanctuary (CWS), Prey Preah Rokar Wildlife Sanctuary (PPRWS), Kulen Promtep Wildlife Sanctuary (KPWS), Siem Pang Wildlife Sanctuary (SPWS), Keo Seima Wildlife Sanctuary (KSWS), Phnom Prich Wildlife Sanctuary (PPWS), Srepok Wildlife Sanctuary (SWS), Lomphat Wildlife Sanctuary (LWS) and Sambor Wildlife Sanctuary (SaWS).

| Year | ATT | CWS | PPRWS | KPWS | SPWS | KSWS | PPWS | SWS | LWS | SaWS |
|------|-----|-----|-------|------|------|------|------|-----|-----|------|
| 2000 |     |     | (8)   |      |      |      |      |     |     |      |
| 2001 | 2^a (29) |     |       |      |      |      |      |     |     |      |
| 2002 | 6^b (69) |     | (1)   |      |      |      |      |     |     |      |
| 2003 | (47) | 1 (40) |      |      |      |      |      |     |     |      |
| 2004 | 62 (36) |     | (1)   |      |      |      |      |     |     |      |
| 2005 |      |     |       |      |      |      |      |     |     |      |
| 2006 | 1 (5) |       | 8 (6) | 17^c | 33^c |      |      |     |     |      |
| 2007 | 4 (3) |       | 37    | 24^c | 20 (1)|      |      |     |     |      |
| 2008 | 4    |       | 2 (1) | 15^c | 13^c |      |      |     |     |      |
| 2009 | 9    | 2    | 13    |      |      |      |      |     |     |      |
| 2010 | 16   | 12   |      |      |      |      |      |     |     |      |
| 2011 | 3    | 2    | 38    |      |      |      |      |     |     |      |
| 2012 | 7    |      |       |      |      |      |      |     |     |      |
| 2013 | 75   | 19   | (1)   | (1)  |      |      |      |     |     |      |
| 2014 | 61   | 4 (1)| 3     | 49   |      |      |      |     |     |      |
| 2015 | 34   | 2 (4)| 2     | 82 (9)| 1    | (11) |      |     |     |      |
| 2016 | 25   | 1    | 3     | 37   | 1    |      |      |     |     |      |
| 2017 | 10   | 1 (4)| 1     | 111  | (2)  | (2)^d| (43)^d|      |     |      |
| 2018 | 13   | (8)  | 1     | 78   | 1    |      |      |     |     |      |
| 2019 | 2    | 23   | 99    | (2)  |      |      |      |     |     |      |
| 2020 | 12   | 63   | 1 (1) | 71   | 1    |      |      |     |     |      |

The first number refers to the number of direct sightings and the number in brackets refers to indirect records (tracks, scats, or second-hand reports); ^aIncludes one observation of remains; ^bIncludes five observations of remains; ^cUnknown if direct/indirect; ^dFaecal survey samples from different dung piles.
The most recent IUCN Red List Assessment for Eld’s deer was conducted in 2015, and it relied on many expert opinions with much of the published information used being approximately 10 years old (Gray et al. 2015a). The assessment describes the Cambodian population of Eld’s deer as one of two numerically significant units, the other being in Myanmar (Gray et al. 2015a). The total population in Cambodia was suggested as being less than 700 individuals, consisting of small, functionally isolated subpopulations (Gray et al. 2015a). Our updated compilation of Eld’s deer records for Cambodia suggests that there has been no improvement, with the total population likely having declined further, with likely less than 400 individuals remaining in Cambodia. Snoul Wildlife Sanctuary, in eastern Cambodia, where Eld’s deer were recorded prior to 2007, was degazetted in 2018, due to habitat destruction, and Eld’s deer are considered lost from this area. We were unable to confirm any recent sightings of Eld’s deer in the northern protected areas of Prey Preah Rokar Wildlife Sanctuary and Stung Treng Ramsar Site, or OuYaDay National Park in eastern Cambodia or Phnom Aural Wildlife Sanctuary in central-western Cambodia: all aforementioned sites have records only between 2000 and 2014. However, this may be due to a lack of survey effort within these sites and does not necessarily mean these subpopulations disappeared. Indeed, at Sambor Wildlife Sanctuary in eastern Cambodia, Eld’s deer were recorded for the first time in five years in 2020 (WWF, internal data). The assertion made by Gray et al. (2015a) that subpopulations at Kulen Promtep, Chhep and ATT in the north and Sreapok in the east may be stabilising or even increasing, despite the limited data, seems optimistic in hindsight, and as reported here, at least in the case of ATT, the subpopulation has declined significantly. ATT is a very small area and the deer population is typically transient, routinely moving in and out of the protected area each season, leaving them more vulnerable to human induced mortality. Thus, it is not surprising that this subpopulation is almost extirpated. Based on the population declines, both recent and projected, for the siamensis subspecies in Cambodia, the new population assessment in Lao PDR (Khotpathoom and Vu 2020), and the pending taxonomic clarification of the siamensis subspecies with the population in Hainan (Wong et al. 2021), an assessment into the status of this subspecies is warranted. Whether a full

**Figure 3:** Minimum counts of Eld’s deer recorded at Ang Trapeang Thmor and Siem Pang Wildlife Sanctuary.

![Figure 3: Minimum counts of Eld’s deer recorded at Ang Trapeang Thmor and Siem Pang Wildlife Sanctuary.](image-url)
re-assessment of the species as a whole is needed is dependent on the other numerically significant population in Myanmar, for which recent population trend data is not consistently available across sites in the literature (McShea et al. 2018; Thu et al. 2019).

Improved enforcement of protected area laws and anti-hunting measures are essential to prevent further population declines and local extirpations. Hunting with guns and dogs, predation of fawns by domestic dogs and mortality in snares remain the greatest threats to Eld’s deer (Gray et al. 2015a). In Keo Seima, a recent study found hunting with dogs was the most commonly reported hunting method (Ibbett et al. 2020), although the high number of snares reported across protected areas is also a major concern (Belecky and Gray 2020; Gray et al. 2017; Groenenberg et al. 2020). Law enforcement patrolling was shown to be inadequate in preventing the spread of poaching activities across Srepok and Phnom Prich, with a simultaneous decline in wildlife coverage detected (Marescot et al. 2020). Furthermore, ranger density is typically lower than an optimal 1 ranger per 10 km², depending on site conditions (Hensor et al. 2016): for example, in the Eastern Plains Landscape, ranger density is 0.41 per 50 km² (Groenenberg et al. 2020). Developing a comprehensive protection strategy and adequately resourcing its implementation is essential to protect populations and must be prioritised. Such a strategy must include increased capacity building in training and leadership for enforcement staff, as well as significant reductions in corruption. The strategy also requires increased levels of law enforcement patrolling in Eld’s deer hotspot areas, domestic dog control within all Eld’s deer range sites and possibly fencing key

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**Table 3:** Camera trap survey results for Eld’s deer at Srepok Wildlife Sanctuary (SWS), Sambor Wildlife Sanctuary (SaWS), Siem Pang Wildlife Sanctuary (SPWS) and Chhep Wildlife Sanctuary (CWS).

| Region   | Protected area | Species/Focal area | Year   | Number of CT sites | Number of CT days | Number of Eld’s deer independent events | Group size |
|----------|----------------|--------------------|--------|--------------------|-------------------|----------------------------------------|------------|
| Eastern  | SWS            | Multi-species      | 2010   | 18                 | –                 | 34                                     | 1–5        |
|          | SWS³           | Waterhole          | 2012   | 5                  | 448               | 7                                      | 1–5        |
|          | SWS            | Waterhole          | 2012–2013 | 13             | –                 | 13                                     | 1–6        |
|          | SWS³           | Waterhole          | 2016   | 54                 | 6,444             | 71                                     | 1–6        |
| Eastern  | SaWS           | Multi-species      | 2015   | 11                 | –                 | 1                                      | 2          |
|          | SaWS           | Multi-species      | 2020   | 11                 | –                 | 1                                      | 4          |
| Northern | SPWS           | Eld’s deer         | 2017   | 38                 | 2,491             | 115                                    | 1–7        |
|          | SPWS           | Eld’s deer         | 2017–2018 | 38              | 4,709             | 139                                    | 1–6        |
|          | SPWS           | Eld’s deer         | 2018–2019 | 40              | 4,026             | 200                                    | 1–4        |
| Northern | CWS            | Multi-species      | 2001   | 7                  | –                 | 6                                      | 1          |
|          | CWS            | Multi-species      | 2002   | 11                 | –                 | 2                                      | 1          |
|          | CWS            | Multi-species      | 2002–2003 | 14              | –                 | 2                                      | 1–2        |
|          | CWS            | Multi-species      | 2004   | 33                 | –                 | 19                                     | 1–3        |
|          | CWS            | Multi-species      | 2005a  | 22                 | –                 | 4                                      | 1–2        |
|          | CWS            | Multi-species      | 2005b  | 72                 | –                 | 1                                      | 1          |
|          | CWS³           | Carnivores         | 2013–2014 | 53              | 5,113             | 0.2³                                   | –          |

³As reported in Gray et al. (2015b); ³As reported in Pin et al. 2018; ³As reported in Suzuki et al. 2017; ³Encounter rate = number of records/1,000 camera trap nights.

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**Table 4:** Transect survey results for Eld’s deer at Keo Seima Wildlife Sanctuary (KSWS), Phnom Prich Wildlife Sanctuary (PPWS) and Srepok Wildlife Sanctuary (SWS).

| Protected Area | Year | Area covered (km²) | Total kilometres surveyed (effort) | Number of Eld’s deer encounters | Group size |
|----------------|------|--------------------|----------------------------------|--------------------------------|------------|
| KSWS           | 2010 | 1,807              | 1600                             | 0                              | 0          |
| KSWS           | 2011 | 1,807              | 1476                             | 0                              | 0          |
| KSWS           | 2013 | 1,807              | 1260                             | 1                              | 2          |
| KSWS           | 2014 | 1,807              | 1292                             | 0                              | 0          |
| KSWS           | 2016 | 1,807              | 1272                             | 2                              | 1–2        |
| KSWS           | 2018 | 1,807              | 1280                             | 1                              | 2          |
| PPWS           | 2010 | 1,670              | 155                              | 0                              | 0          |
| PPWS           | 2011 | 1,670              | 467                              | 0                              | 0          |
| PPWS           | 2014 | 1,670              | 560                              | 0                              | 0          |
| PPWS           | 2016 | 1,670              | 1044                             | 1                              | 2          |
| PPWS           | 2018 | 1,670              | 1130                             | 1                              | 1          |
| PPWS           | 2020 | 1,670              | 1390                             | 0                              | 0          |
| SWS            | 2010 | 1,736              | 273                              | 0                              | 0          |
| SWS            | 2011 | 1,736              | 415                              | 2                              | 1–3        |
| SWS            | 2014 | 1,736              | 603                              | 5                              | 1–3        |
| SWS            | 2016 | 1,736              | 1096                             | 0                              | 0          |
| SWS            | 2018 | 1,736              | 1109                             | 0                              | 0          |
| SWS            | 2020 | 1,736              | 1371                             | 0                              | 0          |

Some of the results presented here were previously published in Groenenberg et al. (2020) and Griffin and Nuttall (2020).
areas that support vulnerable populations, the latter similar to what has been undertaken in Hainan (Zeng et al. 2005). The construction of a fence to protect deer from poaching was instrumental in preventing the extinction of Eld’s deer on Hainan, allowing the extremely small population to recover (Zeng et al. 2005). In addition, rates of prosecution under protected area laws must be significantly increased to provide a greater deterrent to poaching, illegal trade and habitat destruction. For example, at Siem Pang no offender has ever been sent to be prosecuted for killing wildlife, logging or encroachment.

Community engagement is also an important part of reducing the demand for wildlife products, such as Eld’s deer meat and antlers, as well as discouraging poaching and encouraging engagement in more wildlife friendly practices (Steinmetz et al. 2014). This would involve developing widespread sustainable livelihood projects that aim to increase the economic gains of local communities whilst implementing compliance measures that benefit wildlife. Targeted programs could include payment for ecosystem services which incentivizes the sustainable use and conservation of natural resources by local people. An example of a successful program is for “Ibises”, where rice farmers are paid a premium price for their rice in exchange for abiding by a land-use plan and no-hunting rules (Clements et al. 2010). Future interdisciplinary programs require both community participation as well as being evidenced by site-based social-ecological data, which will help develop comprehensive strategies as well as ensuring that anti-hunting strategies are targeted and effective. However, broad scale livelihood initiatives and behaviour change approaches can take time, thus whilst this is a long-term approach that may prove effective, urgent short-term measures should be implemented immediately if remaining populations are to survive. These strategies must involve enforcement of protected area boundaries and zoned areas, and prevention of habitat degradation. While adequate areas of suitable habitat are found within protected areas, the documented decline and loss of Eld’s deer subpopulations due to encroachment and land conversion on the fringes of protected areas indicates that the species is still vulnerable to habitat loss and degradation (Gray et al. 2015a). Habitat improvement within and around remaining Eld’s deer areas, combined with increased law enforcement efforts, may assist in the recovery of Eld’s deer where viable populations remain.

However, some populations may be too small for natural recovery to occur, even if poaching were to cease. In Mae Wong and Khlong Lan National Parks in western Thailand, sambar, muntjac and gaur have shown no indication of recovery despite the sharp reduction in poaching, and it is speculated that past hunting pressures may have reduced population density such that Allee effects may have been induced, resulting in inhibited population growth (Phumanee et al. 2020). Given the indication of very small Eld’s deer subpopulations in Cambodia, a similar problem may be faced by some subpopulations with issues of demographic, environmental and genetic stochasticity, as well as possible natural catastrophes, potentially preventing recovery. Furthermore, very little is known about the genetic diversity of Eld’s deer in Cambodia, and the degree to which subpopulations may have become spatially isolated is unclear. Reinforcement of existing subpopulations by introducing captive bred animals or relocating wild animals from non-viable subpopulations to larger and better protected subpopulations will improve the genetic diversity and help boost subpopulation sizes to facilitate recovery. The benefits and challenges of reinforcing existing populations of Eld’s deer are explored in Gray et al. (2019). In addition to the challenge of securing and relocating suitable individuals, strong inter-agency and inter-organisational cooperation is required for such an undertaking. The sourcing of suitable captive individuals for releasing into the wild is a major challenge, as the existing source of captive animals in Cambodia are not being managed for conservation (Gray et al. 2019). There are currently about 24 Eld’s deer in captivity in Phnom Tamao Wildlife Rescue Centre which originated from just two individuals (Gray et al. 2019). Thailand also has a captive population of the *siamensis* subspecies of ca. 100 individuals, and also have aspirations for reintroduction (Wong et al. 2018). Since low numbers of captive individuals exist, feasibility studies are needed to further identify the most suitable source populations, investigate the potential of different breeding facilities (*in-situ* vs. *ex-situ*) and the resources and capacity available in potential captive breeding centres. Additionally, the demography, health and genetic variation of remaining captive and wild populations will need to be assessed to support a corrective mating program and to avoid inbreeding depression. Moreover, the success of any program to supplement existing populations is dependent on the mitigation of identified threats to the wild populations, community support, strong law enforcement and the robust management of the reinforced populations.

This review shows there is a clear lack of suitable monitoring methods in place for Eld’s deer in Cambodia, with existing approaches unable to provide population estimates, or even reliable trends. Effective monitoring is difficult due to the rarity of the species, but the use of camera traps may provide a suitable option, as they have successfully been used to estimate the populations of rare
species, with different analytical options available. Due to the low density at most sites, it may not be possible to estimate the population size at all locations. However, a standardised method with sufficient survey effort would at least allow comparisons of indices to estimate trends and relative abundance, as well as provide insights into distribution and habitat use. While there is a need to develop an appropriate monitoring method, this must not be allowed to inhibit or delay immediate conservation actions, and should be considered an essential complementary activity to assess the effectiveness of actions undertaken and to improve knowledge. The data collated in this review is sufficient to show the urgency of the situation and guide the immediate planning and implementation of actions at key sites, which should include adequate monitoring. Further investigation is needed to determine whether Eld’s deer have disappeared from sites that presence was previously recorded at, and at sites that support areas of suitable habitat but have limited resources to survey vast areas of forest. As an understudied species, especially in Cambodia, conservation strategies would greatly benefit from the adoption of a standard methodology for monitoring as well as research conducted into aspects of Eld’s deer life history, behaviour, diet, habitat preferences and requirements, in addition to the impact of fire and a changing climate. This is essential for the development of evidence-based conservation strategies to preserve the small remaining populations.

6 Conclusions

Eld’s deer in Cambodia are persisting in very small populations in at least nine protected areas in the north and east of the country, which have at least one recorded encounter since 2015. Based upon the data available, Siem Pang may support the largest remaining Eld’s deer population in Cambodia. However, no accurate population estimates are available and population trends at most sites are unclear. Eld’s deer has clearly declined at ATT since 2014, where its imminent extirpation is predicted under a business-as-usual scenario. Current longitudinal methods at Keo Seima, Srepok and Phnom Prich in eastern Cambodia have failed to produce estimates due to an insufficient number of detections, indicating remaining populations are severely depressed. Given the levels of illegal hunting, it is presumed that Eld’s deer is declining across the majority of sites, although there is insufficient information to confirm this. We suggest Cambodia’s total population of Eld’s deer may be less than 400 individuals.

The conservation of this species requires urgent action today and we suggest the following priorities should be adopted:

- Implementation of an effective law enforcement and anti-hunting strategy at key sites for the species, as well as targeting wildlife trade localities
- Feasibility studies on the potential for captive populations to support conservation of the species in the wild in Cambodia and the possibility of re-populating wild populations
- Formulation, implementation and enforcement of management and zonation plans across all protected areas, including demarcation of protected area boundaries
- Development and expansion of sustainable livelihood programs that contribute to economic development and wildlife friendly practices in local communities around critical Eld’s deer populations
- Development of standardised camera trap surveys at all sites, for effective monitoring
- Research into Eld’s deer ecology and threats to facilitate effective conservation planning and management
- Feasibility studies on the potential for physical or virtual fencing of key sites, or critical areas within sites, to protect core subpopulations from illegal hunting and domestic dogs.

Although our findings cannot provide robust results, the review of literature and available records shows the future of Eld’s deer in Cambodia is bleak. However, with urgent, targeted action to prevent the illegal activities that threaten them, and concerted conservation action to support population recovery, the future of this species in Cambodia may yet be secured.

Research ethics: Ethics approval was not required for this review, with data used either available in the public domain or not requiring such approval in Cambodia due to being observational.

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