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Review: The status of the endangered Eld's deer (*Rucervus eldii*) and conservation actions in Thailand

RONGLARP SUKMASUANG[1,♥], NARIS BHUMPAKPHAN[1], WILLIAM J MCSHEA[2], WORAWIDH WAJJWALKU[3], BORIPAT SIRIAROONRAT[4], SUMATE KAMOLNORANART[5], MARNOCH YINDEE[3] TARASAK NIPANAN[6], BANPOT MALEEHUAN[6], KRITTAPHAS KHANTHATHONGSAKULDEE[7], CHATTRAPHAS PONGCHAROEN[1], NANTIDA SUTUMMAWONG[1], WARISARA THOMAS[1]

[1]Department of Forest Biology, Faculty of Forestry, Kasetsart University. 50 Phahonyothin Road, Chatuchak District, Bangkok 10900, Thailand. Tel.: +66-2-579-0176, Fax.: +66-2-942-8107, ♥email: mronglarp@gmail.com

[2]Conservation Ecology Center, Smithsonian's National Zoo and Conservation Biology Institute. 3001 Connecticut Ave., NW Washington, DC 20008, United States of America

[3]Small Animal Teaching Hospital, Akkhraratchakumari Veterinary College, Walailak University. 222 Tambon Thaiburi, Amphoe Tha Sala, Nakhon Si Thammarat Province 80161, Thailand

[4]Faculty of Environment and Resource Studies, Mahidol University. 999 Phutthamonthon Sai 4, Salaya, Phutthamonthon, Nakhon Pathom Province 73170, Thailand

[5]The Zoological Park Organization of Thailand. 267/1 Pracharat Sai 1 Road, Bang Sue Subdistrict, Bangkok 10800, Thailand

[6]Wildlife Breeding Group, Wildlife Conservation Office, Department of National Parks, Wildlife and Plant Conservation. Chatuchak District, Bangkok 10900, Thailand

[7]Wildlife Conservation Division Conservation Area Administration Office 16, Chiang Mai. 153 Charoen Prathet Road, Chang Khlan Subdistrict, Mueang Chiang Mai District, Chiang Mai 50100, Thailand

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Abstract. *Sukmasuang R, Bhumpakphan N, McShea WJ, Wajjwalku W, Siriaroonrat B, Kamolnoranart S, Yindee M, Nipanan T, Maleehuan B, Khanthathongsakuldee K, Pongcharoen C, Sutummawong N, Thomas W. 2022. Review: The status of the endangered Eld's deer (*Rucervus eldii*) and conservation actions in Thailand. Biodiversitas 23: 5020-5034.* The endangered Eld's deer (*Rucervus eldii* McClelland, 1842) once roamed throughout the plains and dry forests of South and Southeast Asia. However, due to heavy poaching and habitat loss, the population has declined drastically and has disappeared from many of its historical ranges. They are presently found in some natural areas of India, Myanmar, Cambodia, Lao PDR, and Hainan Island, China. Thailand used to be the distribution center of the species, where two subspecies, the *R.e. thamin* and *R.e. siamensis*, were found. However, both subspecies have disappeared from the natural resources of Thailand since the early 1990s. Many conservation programs have been conducted to save this species in Thailand, such as captive breeding and reintroduction. Our literature review revealed that currently, more than a thousand *R.e. thamin* are housed in over 20 wildlife breeding facilities and 109 *R.e. siamensis* in 8 breeding facilities. Based on the workshops on conservation and restoration of the species, suitable genetic selection can create populations suitable for return to protected forest areas in Thailand. At present, more than 554 *R.e. thamin* have been released back into the wild in 8 wildlife sanctuaries, 3 national parks and 1 non-hunting area and 27 *R.e. siamensis* were released in 2 wildlife sanctuaries in Thailand. The follow-up of the deer in the release areas was flawed. Major knowledge gaps include recent trends in the population dynamics, habitat selection, diet items and threats. Identifying and restoring suitable dry forest habitats for reintroduction are also keys for species conservation.

Keywords: Eld's deer, endangered species, reintroduction, *Rucervus eldii siamensis, Rucervus eldii thamin*

INTRODUCTION

Captive breeding programs, and the associated translocation of wildlife, represent a powerful tool for conservation management (Lott et al. 2020; Khattak et al. 2020). Reintroduction is an important tool for achieving the long-term conservation of endangered species (IUCN/SSC 2013; Stewart et al. 2017; Valente et al. 2017; Zhang et al. 2019; Riga et al. 2022). The Eld's deer or brow-antlered deer (*Rucervus eldii* McClelland, 1842), is an endangered cervid that lives in lowland areas with dry dipterocarp and mixed deciduous forests (Gray et al. 2015; McShea et al. 2018; Thu et al. 2019; Wong et al. 2021; Ladd et al. 2022). They are found in the Indo-Burma hotspot region and are currently distributed in 7 countries, including India, Myanmar, Thailand, Lao PDR, Cambodia, China, Vietnam and Cambodia (Gray et al. 2015). Eld's deer has been categorized as endangered since 2008 (Gray et al. 2015), with an overall population estimate of 5500-6700 deer left in the wild (Wong et al. 2021). The species was once highly distributed throughout the North, West and Central parts of Thailand (WWF 2013, 2014; Thu et al. 2019), however, they became extirpated from the wild due to hunting pressure and habitat loss and have been a National Reserved Species since 1960 (Bhumpakphan et al. 2003).

There are three recognized subspecies of Eld's deer (McShea et al. 2018). The first subspecies, Sangai or Manipur brow-antlered deer (*R.e. eldii*) is bound to a single

wetland in India. The second, Siamese Eld's deer (*R.e. siamensis)* was extirpated from Thailand and Vietnam, with scattered reports in Lao PDR and Cambodia. The third, Thamin or Burmese brow-antlered deer (*R.e. thamin*), was extirpated from Thailand, with the largest remaining wild population in Myanmar (McShea et al. 2018). The population is currently in decline, with very few left in the wild (Ladd et al. 2022). The Hainan Island Eld's deer population in China has at times been considered a separate subspecies *Rucervus eldii hainanus*; however genomic studies are still ongoing and it is still considered as a subpopulation of *R.e. siamensis* (Balakrishnan et al. 2003; Wong. 2021).

Thailand was historically the center of distribution of Eld's deer containing 2 subspecies, *R.e. siamensis* and *R.e. thamin* (Bhumpakphan et al. 2003; McShea et al. 2018; Pumpitakkul et al. 2021). The last reported Eld's deer sighting in the natural forests of Thailand was in 1984 in Huai Kha Kheang Wildlife Sanctuary (HKKWS) and the last record of an Eld's deer carcass in Thailand was of one hunted in 1993 and brought to Nan province (Bhumpakphan et al. 2003).

Like other areas in the Southeast Asia region, there are disturbances in natural habitats, including the transformation of natural lowland areas into agricultural land, resulting in habitat loss and reduction of wildlife populations (Austin et al. 2017; Allan et al. 2019; Ripple et al. 2019). Agriculture is considered as the dominant driver of forest conversion across the tropics, accounting for more than 70% of deforestation (Hosonuma et al. 2012). Southeast Asia has the greatest rates of deforestation and the lowest proportion of forest cover remaining (Wilcove et al. 2013; Heino et al. 2015; Marescot et al. 2020). Almost all remaining forests are subjected to differing levels of illegal hunting (Harrison et al. 2016; Hughes 2017). It is, therefore, unsurprising that large to medium-bodied mammals in Southeast Asia have extirpated from more than 80% of their geographic ranges (Duckworth et al. 2012) and have undergone significant population losses (Dirzo et al. 2014; Benítez-López et al. 2017; Ceballos et al. 2017; Gallego-Zamorano et al. 2020). Poachers have also developed new hunting methods, including steel and wire traps, which are used effectively throughout the species range (Gray et al. 2017, 2018; Evans et al. 2020; Belecky and Gray 2021; Figel et al. 2021; Gray et al. 2021). The ungulates are targeted for their meat, as well as for pest control, as they sometimes forage in agricultural crops (Ripple et al. 2015), while large carnivores, porcupines and birds are targeted by poachers for sale (Heinrich et al. 2020) which causes wildlife to be seriously threatened in Southeast Asia (Harrison et al. 2016; Wolf and Ripple 2017; Benítez-López et al. 2019). Like other large wild animals in the plains of Southeast Asia, Eld's deer is in a drastic decline in all range countries due to the deterioration of their habitat and poaching (Gray et al. 2015; Ibbett et al. 2020). Recovery of ungulates in overhunted South-East Asian reserves requires intensive interventions, particularly habitat improvement and population augmentation (Steinmetz et al. 2014; Vongkhamheng 2018; Jornburom et al. 2020; Phumanee et al. 2020).

This species has constantly been a species of interest in population restoration with breeding and reintroduction to the wild. From 1983 until 2022, more than 544 Eld's deer have been released in at least 12 protected areas that previously reported the presence of wild Eld's deer (Bhumpakphan et al. 2018; ZPO 2022). Bai et al. (2021) and Zhang et al. (2021a) concluded that the restoration of the Père David's deer (*Elaphurus davidianus*) population in China was a successful example of ex-situ conservation. After 39 deer were reintroduced to Dafeng in 1986, the population expanded to 78 in 1990 and to 5016 by the end of 2019. Over the last 35 years, a total of 546 deer have been sent to other locations as of January 2021. However, the rate of reintroduction success varies across species and differs among regions, and generally, the poor performance of reintroduction is reported due to different factors (Robert et al. 2015; Thévenin 2019).

Few mentions of the Eld's deer conservation perspectives and restoration in Thailand were found. Ex-situ conservation is an important part of the Convention on Biological Diversity, one of the objectives of the Aichi Biodiversity Targets (Ford et al. 2020; Bai et al. 2021) and a strategic task and priority action of the Thai Wildlife Conservation and Action Plan (2021-2030) (Faculty of Forestry 2020). Eld's deer restoration activity in Thailand has been in intensive operation for nearly three decades in the protected areas of the country. Therefore, this academic review will be a guideline for future actions in the conservation and restoration of this endangered species. The purpose of this paper's review study was to confirm the importance of the conservation of Eld's deer in Thailand. This will help to clarify the guidelines for the conservation of this species. Our goal here is to identify the knowledge gaps focused on Thailand and other regions concerned.

We reviewed all the searchable literature using the scientific terms and the common names of the *R.e. thamin*, *R.e. siamensis* and *R.e. eldii* subspecies, as well as the following keywords: Eld's deer, population, habitat, ecology, distribution, behavior, reintroduction, post-release of Eld's deer. The literature included peer-reviewed articles, scientific reports, dissertations, conference proceedings and internal reports of related organizations. Information gathered was analyzed and summarized by thematic topics. Based on the 152 publications concerned, 48 were related to *R.e. siamensis* and *R.e. thamin*, 32 of which were published in international journals. The documents belong to 20 author teams and 7 are nationally published documents. Details on the various areas reviewed are shown in Table 1.

TAXONOMY

Eld's deer belongs to the order Artiodactyla, family Cervidae, subfamily Cervinae and tribe cervini. Eld's deer share morphological resemblances with swamp deer (*R. duvaucelii*) and the extinct Schomburgk's deer (*R. schomburgki*) (Ghazi et al. 2021). The species is classified in the genus *Rucervus*, which is currently adopted by the International Union for Conservation of Nature (Gray et al. 2015).

Table 1. Number of publications by thematic topics on *R.e. siamensis* and *R.e. eldii*

Study areas of interest	Intl. journals	No. of author teams	National language
Conservation status	6	2	0
Habitat management	5	3	1
Ecology of released Eld's deer	5	1	1
Population and genetic	5	1	0
Captive management	4	1	0
Reintroduction	3	5	2
Reproductive management	2	1	0
Climate change	1	1	0
History evolution	1	0	0
Population viability analysis	0	1	1
Distribution	0	1	0
Husbandry	0	1	0
Monitoring	0	1	1
Feeding behavior	0	1	1
Total	32	20	7

However, Ghazi (2021) has suggested that the three species classified under the genus *Rucervus* (*R. duvaucelii*, *R. schomburgki* and *R. eldii*) are extremely different and the classification of Eld's deer in *Rucervus* is phylogenetically inappropriate. Contrary to different perspectives based on morphological and karyotypic classification, molecular studies based on mitochondrial and nuclear markers suggest that the placement of Eld's deer along with several other species, including *Elaphurus davidianus*, *Przewalski albirostris* and all species of the genus *Rusa*, to the genus *Cervus* is phylogenetically more appropriate (Hu et al. 2019). Recent phylogenetic analysis has revealed an ancestral divergence of the common ancestors of the *Axis* and *Rucervus* sp. groups from the main phylogenetic lineage of the tribe *cervini*, which later radiated in the genus *Cervus*, *Rusa*, *Elaphurus* and Eld's deer (Heckeberg et al. 2022). Based on its ancestral divergence, Eld's deer is phylogenetically more closely related to the genus *Cervus* than to *Rucervus*, and the morphological similarities with *R. duvaucelii* and *R. schomburgki* characterize convergence rather than phylogenetic relatedness (Ghazi et al. 2021).

Analyses of mitochondrial data have placed Père David's deer (*Elaphurus davidianus*) as the sister taxon to Eld's deer (Heckeberg et al. 2022). Recent studies, four based on genetics and another on antler morphology, have suggested that Eld's deer is actually more closely related to Père David's deer than to species of the genus *Rucervus* (Hassanin et al. 2012; Turvey et al. 2017; Heckeberg 2020; Samejima and Matsuoka 2020; Ghazi et al. 2021).

The Eld's deer is known from the Middle Pleistocene of Thailand. Fossils of Eld's deer were collected from the caves of Thum Wiman Nakin and Kao Pah Nam and from the Khok Sung sand pit, northeast Thailand (Suraprasit et al. 2016). *R.e. siamensis* exhibits two divergent mtDNA lineages (mainland and Hainan Island), which diverged around 0.2 Mya, possibly driven by the fluctuating sea levels of the Early Holocene period (Ghazi et al. 2021). The divergence between *R.e. eldii* and *R.e. siamensis* occurred around 0.4 Mya, potentially associated with the adaptations to warm and humid climate with open grassland vegetation that predominated in the region (Ghazi et al. 2021).

Three distinct Eld's deer subspecies have been identified, including, (i) Manipur brow-antlered deer (*R.e. eldii*) or Sangai in native tongue; (ii) Siamese Eld's deer (*R.e. siamensis*), also known as Lamang in Thai, Ong Mang in Lao PDR, Ramiang in Khmer language, Ka-tong in Vietnamese, and Yanji in the Moi tribe language; (iii) Burmese brow-antlered deer (*R.e. thamin*) or Thamin (Gray et al. 2015; Angom et al. 2017; Ghazi et al. 2021) (Figure 1). Although Angom and Hussain (2013) and Wong et al. (2018) have suggested that the Eld's deer population on Hainan Island, China, also known as Polu in native Chinese, should be identified as a separate subspecies, the Hainan Eld's deer (*R.e. hainanus*), however, there is still an ongoing dispute with genetic studies being conducted and this population is still considered a subpopulation of the Siamese Eld's deer (Balakrishnan et al. 2003; Gray et al. 2015; Wong et al. 2021).

GENERAL BIOLOGY AND ECOLOGY

General characteristics

Eld's deer are medium size deer, weighing approximately 90-150 kg (Gray et al. 2015), similar in size and shape to the barasingha (*Rucervus duvaucelii*) (Kumar et al. 2021). The body length is approximately 1.5-1.7 m with a shoulder height of 1.2-1.3 m. They have tight, fine, yellowish-brown fur along their body, with a reddish-brown upper coat and white fur on the belly and around the ears, eyes and chin. During the breeding season, the fur around the neck of the male grows into a long, brown mane. In the hot season, the male disappears, and the fur changes color to dark brown. Newborn fawns have white spots along the body, which fade away when they get older. Some females still have faded spots even when they are adults. Males have bow-shaped antlers that regrow and are shed every year, with the largest size being attained during the breeding season (Gray et al. 2015).

General behavior

Direct observation of the behavior shows that Eld's deer are very fearful animals. However, direct observation is quite difficult to conduct, as the behavior most seen is dodging by running and leaping away. The Eld's deer that do not have strong vigilance and escape behavior is more likely to be hunted by natural predators than those that are vigilant and good at escaping (Buranapim et al. 2008). In Myanmar, ancestor Eld's deer are found resting in open areas of dry dipterocarp forests (Aung et al. 2001). Many studies have been conducted on the foraging behavior of Eld's deer (Tuboi and Hussain 2014). They inhabit monsoon forests and grasslands and are more grazers. However, they also eat large varieties of plants, foraging on their shoots and leaves, as well as some species of flowers and fruits (Pan et al. 2014; Wong et al. 2021).

A B C

Figure 1. The morphology of *Rucervus eldii*: A. *R.e. eldii* (Zahrada Zoo, Praha), B. *R.e. siamensis* (Nakhon Ratchasima Zoo, Thailand), C. *R.e. thamin* (Khon Kaen Zoo, Thailand)

Aung et al. (2001) found that *R.e. thamin* mainly uses areas in dry dipterocarp forest, but they change their preference with the seasons and have different characteristic ways of using the habitat. In the non-breeding season, female ancestor Eld's deer in Myanmar are more commonly seen in degraded forests and near farmlands than males (Aung et al. 2001). This may be because the female chooses areas that are less vulnerable to predators or because of the need for more valuable food to produce milk (Aung et al. 2001).

Reproduction and rearing of the young

Reproductive activity takes place from February to June, and 80% of births occur between September and November (Pan et al. 2011). The reproductive stage of females extends from 2-12 years old, while the males also begin at 2 years old (Aung et al. 2001). They have a gestation period of 8 months, usually giving birth to one fawn every two years but rarely giving birth to twins. During the natural breeding season, the male Eld's deer will have fully grown antlers and a long-grown out mane (Gray et al. 2015). Fighting between males is seen during this period to establish dominance in the herd and mate with the females. Loud and long vocalization can also be heard from the breeding males during this time (Gray et al. 2015). The females rear their young for 4 months before they are ready to return to the mating cycle. The birth season occurs from early September to early February. However, 80% of births occurred in a 10-week period from September to December. Seventeen births were recorded in a period of 24 weeks from September to February with 80% occurring in a period of 12-week from September to November (Song and Zeng 2003).

POPULATION AND DISTRIBUTION

A recent estimate put the global population at 5500-6700 (Wong et al. 2018). The population is declining, so if effective conservation measures are not implemented immediately, some of these populations could soon be wiped out, and the species may once again warrant a critically endangered status (Wong et al. 2018, 2021). Wong et al. (2018) also suggested that, at the species level, the estimated ancestral wild population is 3500-4700, with another 2000 or so in other states.

Of the subspecies, only *R.e. thamin* has a population exceeding a thousand (Gray et al. 2015). All ancestral wild populations of Eld's deer are declining rapidly (Wong et al. 2018). The Hainan population consists of 700-800 individuals primarily considered to exist in a semi-wild capacity (Wong et al. 2018). Manipur's brow-antlered deer is the most localized cervid species found in India, occurring as a single isolated population in Keibul Lamjao National Park, Manipur (Angom et al. 2017), with the population in the wild being 260 deer in 2016 (Singh and Khare 2018).

Singh and Khare (2018) reported that from the 22 consecutive population surveys conducted from 1975 to 2016, there was a tendency for the population to increase. Fourteen Sangai were found at the beginning of the survey in 1975, and 260 were found in 2016. The distribution of Eld's deer ranges from the north-eastern part of India in Assam state to Myanmar, Thailand, Lao PDR, Cambodia, Vietnam and China in Hainan Island (Gray et al. 2015). Thailand was the center of distribution of the Eld's deer (Ghazi et al. 2021) as it has 2 subspecies, the *R.e. siamensis*, once found in the northern, central and north-eastern regions of Thailand, and the *R.e. thamin* found in the western part of the country (Bhumpakphan et al. 2003). The divergence between *R.e. thamin* and *R.e. siamensis* deer took place around 0.4 Mya during the Late Pleistocene and Early Holocene periods (Tripathi et al. 2018). This species was once abundant in the sparse forests in every part of the country, except in the south. However, since the early 1990s, the Eld's deer have been hunted to extinction from all of their natural habitats in Thailand (Gray et al. 2015). Currently, the Eld's deer population and their distribution are found in only 7 countries as follows.

India

India is the distribution site of the Manipur or Sangai subspecies of Eld's deer found only in Kaibul Lumjao National Park (Ghazi et al. 2021). The area is approximately 40 km^2, located near the border of Myanmar. The area is mostly marshland, lakes, and terrestrial forests. The record of Lieutenant Percy Eld in 1838 described that after a grassland fire, a large herd of 200-300 deer was seen and 100 years later, the Sangai was

believed to have gone extinct from the Kaibul Lumjao. However, they were rediscovered in the same area in the 1950s. The subspecies feed on floating vegetation in the middle of the lake known as Phumdi. There is an attempt to find a second area to support the Sangai population (Singh and Khare 2018).

Myanmar

This country is home to the subspecies Thamin, which in 1992 had a total of 2200 deer in the forests of 28 provinces. Until the present, the population trend has been in decline, with 6 populations found in 23 sites, 5 of which are found in the forest complexes on the west bank of the Ayeyarwady River and one in the area on the east bank of the Ayeyarwady River. The total population is approximately 1500 individuals, most of which are in Chatthin (CWS) and Shwesettaw Wildlife Sanctuaries (SWS), the two important sources of Thamin in Myanmar (Aung et al. 2001). Thu et al. (2019) reported that across the 18-years period from 2001 to 2018, 2372 Eld's deer were observed. The adult female population was the predominant age and sex class, followed by adult males and fawns. The adult male to female sex ratio was 0.4:1.0 between 2001 and 2018, slightly skewed towards females. They also found that the fawn to adult female ratio showed a significant positive relationship with the increasing population density of Eld's deer during these 18 years. Bowler et al. (2019) estimated that the population size of Eld's deer in SWS is c. 1519 (1061-2114), suggesting it is the world's largest wild population. The mean group size and crowding of Eld's deer for the hot, dry season in Myanmar were 7.6 and 11.1, respectively. The population of Eld's deer in SWS has increased steadily during these 18 years (Thu et al. 2019).

Thailand

The ancestral wild populations in Thailand are likely extinct (Wong et al. 2018). Thailand used to be the central geographical range of Eld's deer (Gray et al. 2015). Two subspecies used to exist in Thailand. Siamese Eld's deer was found in the north, central, northeast and southeast parts of the country. Thamin was found in the west along the eastern Downa Range and the upper Tenassarim range in Thailand near the Myanmar border. In the 1980s, shed antlers of Eld's deer were found in a forest near Mae Sod, Tak Province (Bhumpakphan et al. 2003). The last 2 reports were in HKKWS, in 1984 and at the forest area adjacent to Sirikit Dam, Na Muen District, Nan province, in 1993.

Lao PDR

Eld's deer are found distributed in the plains along the Mekong River Basin (WWF 2013, 2014). They were once seen in Tha Khek, Xe Khong forest, and Xe Pian National Protected Area. The population has been continuously threatened for the past 60 years (Bhumpakphan et al. 2003). Currently, the Eld's deer population is found in 2 areas. The first population with 30 deer is found in Sonnabuli, Savannakhet. The second population was found in Dong Kanthung Forest, Mun La Pa Mok Town, Champasak province, but the exact number is not yet known. Khotpathoom and Vu (2020) estimated the total number of Eld's deer in the surveyed area of the Xonnabouly Eld's Deer Sanctuary to be 173, using the line transect method. Lao PDR has only one country that confirmed population and this was recently estimated (Khotpathoom and Vu 2020). Report of natural encounter was at Nong Kasang in Dong Kanthung Proposed National Biodiversity Conservation Area, Champasak province, Lao PDR (Trisurat and Bhumpakphan 2018).

Cambodia

Eld's deer used to be abundant in the open fields and dry dipterocarp forests of Cambodia with other wildlife species (Pin et al. 2018; Rostro-García et al. 2018). The Ramiang population was severely threatened by hunting pressure (Bhumpakphan et al. 2003; Gray et al. 2012). The species declined by 90% or more during the first decade of the 21st century (Srun 2018). Weiler (2004) reported the number of Eld's deer from various methods and estimated that about 200-400 deer are remaining in Cambodia. They are currently found in 9 natural areas, especially in two forests in Preah Vihear province, including Kulen Phromthep Wildlife Sanctuary and Chhep Protected Forest. They were important conservation sites with populations of up to 60 deer each (Weiler 2004). However, no accurate population estimates are available and population trends at most sites are unclear. Eld's deer has clearly declined at Ang Trapeang Thmor since 2014 (Ladd et al. 2022). Gray et al. (2015) estimated that the Siamese Eld's deer population in Cambodia had declined by 90% or more in the 2000s. Report of the natural encounter was in Chhep Protected Forest, Preah Vihear province, Cambodia (Trisurat and Bhumpakphan 2018).

Vietnam

The Eld's deer population was found living in deciduous forests in the Tay Nguyen Plateau in the middle of the country. During the colonial days of France, there was a report that in 1937, five Eld's deer were transported to the Paris Zoo. In 1992, the Eld's deer were seen in five areas of deciduous forests in central Vietnam near the border with Lao PDR and Cambodia, continuing down south (Bhumpakphan et al. 2003). Between 2001 and 2003, traces of Eld's deer, such as scat, hoof prints, and shed antlers, were found at Chu Prong proposed nature reserve and shed antlers were found at Yok Don and Chu Mom Ray National Park. Currently, there has been a total of 19 protected forest areas declared in the former Eld's deer distribution range however, there are currently no reported sightings. The ancestral wild populations in Vietnam are likely extinct (Wong et al. 2018).

Hainan Island, China

Eld's deer were once found distributed throughout Hainan Island. In the 1950s, as many as 5000 deer were seen, but that number dropped to 500 in 1964. Heavy poaching in the 1960s caused the population to drop to 26 in 1976. In the same year, Datian Eld's Deer National Reserve was established as a fenced area in Dong Fang.

The bottleneck population increased to 500 in 1983 and 700 in 1996. Later, when the area was expanded to 13.14 km^2, the population increased to more than 1000 in 2003 (Pan et al. 2014). In the early 1990s, there were plans to translocate 180 Eld's deer to Bangxi, Ganshiling, Tunchang and other Nature Reserves in Hainan County or Hainan Island, as well as to Shanghai Zoo, and in 2004, 20 Eld's deer were released in Mihouling Mountain Nature Reserve in Dongfeng City. The deer were radio-collared for post-release monitoring and cooperation was also established with the community to protect the Eld's deer. There are also 35 captive deer kept in 3 zoos (Chan 2018).

SELECTED HABITAT FOR REINTRODUCTION

Eld's deer, like banteng, are specialists of the dry forest (McShea et al. 2019). Fire ecology is of critical importance to the thamin subspecies (McShea et al. 2018). The dry deciduous dipterocarp forests (DDF) are maintained through the extensive fire, and the cycle of regeneration for grasses is driven by the frequency and intensity of fires (McShea 2004). Dry forests occur on all continents in the tropical and sub-tropical zones under monsoonal climates, where dry seasons last for at least five months (Allen et al. 2017; Singh and Chaturvedi 2018). The DDF is a key forest type in Asia, extending from the tropical to the subtropical regions in Southeast Asia (Bunyavejchewin et al. 2011; Wohlfart et al. 2014). In 2011, approximately 156000 km² of DDF remained in Southeast Asia (Wohlfart et al. 2014). The highest DDF coverage is in Myanmar (79000 km²), Thailand (37000 km²), and Cambodia (23000 km²), whereas little DDF is left in Lao PDR and Vietnam. Consequently, preserving the DDF in the remaining protected areas is key to preserving Eld's deer in Southeast Asia (McShea et al. 2005).

Based on tracking the released Eld's deer in many areas of Thailand, including WLWS, SLPWS, HKKWS, MPNP, it was found that even if the release was carried out in areas away from the human communities more than 10 km, but found that some released Eld's deer regularly traveled to live in the areas near the villages. There was a risk of being hunted or bitten by domestic dogs that had to be taken back to the release areas or put back into the captive. However, most of the released Eld's deer population continued to home in the released area for many years until the present. That is similar with the study on the habitat use of reintroduced Eld's deer on Hainan Island. They were found to be active around villages that maintained traditional agricultural practices (Pan et al. 2014). The distance of reintroduced deer from villages was small, not only compared with their daily movements but also compared with the distances that other populations or deer species maintain from infrastructure (Pan et al. 2014). Both sexes of the deer were more abundant in the manipulated habitat from January to May, with males being more abundant in the natural habitat from September to October. However, females were significantly more abundant from April to May in the manipulated habitat. The deer preferred the more open, manipulated habitat for feeding, consistent with greater food availability (Zhang et al. 2019).

They usually do not like to live in dense forests, especially the males, because of the long brow tine, front branch of the antlers, pointing to the front of its head and the main beam, curved from hind to front, with small branches, causing the antlers to often intertwine with branches and vines when going into dense forests (Stenhouse et al. 2005). The habitat use of Eld's deer is relatively more similar to Chital (*Axis axis*) of similar size than that of large-bodied Sambar (*Rusa unicolor*) and that of small-bodied red muntjac (*Muntiacus muntjak*) (Bhattarai and Kindlmann 2018). The habitat selection of reintroduced Eld's deer was scale-dependent; human disturbance had a strong influence on the habitat selection of Eld's deer (Yan et al. 2013). Therefore, the improvement of habitat in the released areas must be carried out continuously. Fire is an important tool for improving habitat during the dry season both, increasing the high quality of forage plant species that occur after the fire. It also creates enough open areas for some habitats for the species activities that depend on their natural history (McShea et al. 2005).

THE CAPTIVE AND REINTRODUCED POPULATION IN THAILAND

In 1974, a 3-year-old female *R.e. siamensis* from Southern Lao PDR was donated to the Royal Forest Department of Thailand and was housed at Khao Kheow Wildlife and Nature Education Center, located in the eastern part of Thailand. At that time, the Royal Forestry Department, Thailand, had requested *R.e. siamensis* semen from Paris Zoo for artificial insemination, however, results from this request were not recorded. Later, two *R.e. thamin* males, each aged 1.5 years, were requested from the National Zoological Park in Washington, DC, United States and arrived in Thailand in 1978. Due to a lack of clear understanding and mismanagement, the deer were paired up, forming a mixed herd between *R.e. siamensis* and *R.e. thamin*. The first hybrid fawn was born in 1979; however, it did not survive. Later, in 1980, the second male fawn was born. Followed by two more fawns, one male and one female, born in 1981 and 1982, respectively. Later, this group of the Eld's deer was kept at the Khao Kheow Wildlife and Nature Education Center until all of the hybrids have extirpation.

The pure *R.e. thamin* males were moved to Bang La Mung Wildlife Breeding Center in Chonburi province and were mixed in with the herd of *R.e. thamin* that were kept in a large enclosure surrounded by forest and have become a large herd of untamed deer (Bhumpakphan et al. 2003).

In 1983, the Zoological Park Organization (ZPO) received 11 *R.e. thamin* from a private collector, which were sent to Khao Kheow Open Zoo (KKOZ) and became the founders for the captive reproduction program for the Thamin subspecies (Bhumpakphan et al. 2003). The deer bred successfully, producing many offspring annually. New founders were also brought in from other sources, including local private organizations and from abroad.

Some of these deer were transferred to other zoos and DNP wildlife breeding centers. Over the years, the number of *R.e. thamin* at KKOZ has increased to more than 200 animals and surplus control had to be conducted by separating males and females, leaving only a few that were selected for breeding. From the population survey of captive *R.e. thamin* in 2004, a total of 331 deer were counted in 4 zoos under the ZPO, 222 deer in 11 DNP wildlife breeding centers and 271 deer in 4 private zoos, adding up to 824 animals in 2004 (Kamolnarranath et al. 2004).

In 1984, Dusit zoo received a pair of *R.e. siamensis* that reproduced and gave birth to their first fawn in 1986. These deer reproduced actively and gave birth to offspring every year. Later, one of the male offspring replaced its father to become the alpha male. The female and male founders lived for approximately 20 years, and both died in 2004. Their offspring continued to inbreed and neonatal mortality increased.

In 1987, a 1-year-old male *R.e. siamensis* was brought into Bang Phra Wildlife Breeding Center, Chonburi province, and was then sent to Bang La Mung Wildlife Breeding Center in Chonburi.

In 2003, two females aged 6 and 4 years old of *R.e. siamensis* from Dusit Zoo were sent to the breeding center and started to reproduce, forming the second herd of captive *R.e. siamensis* in Thailand (Kamolnarranath et al. 2004).

In 2015, 2 male and 2 female deer from this herd were sent back to Dusit zoo as new founders for the first herd (ZPO 2022). However, the problem of these *R.e. siamensis* herds was that they started from only 3 founders, 2 paternal and 1 maternal line, which is too limited to keep a viable population in the long term (Thongphakdee et al. 2018).

In 2018, there were at least 1019 Thamin Eld's deer in captivity at 20 sites and at least 106 Siamese Eld's deer in captivity at 8 sites in Thailand (Thongphakdee et al. 2018). Thongphakdee (2012, 2017) reported Eld's deer embryos produced in vitro can develop and subsequently, the Eld's deer was released back into the wild in Salak Pra Wildlife Sanctuary (SLPWS).

In 2019, the total number of *R.e. thamin* in government zoos was 493 deer, and breeding centers were 595 deer, with a total population number of 1088 deer, which included populations for educational display, breeding and conservation programs as candidates for reintroduction (ZPO 2022). The deer were moved to different zoos and wildlife breeding facilities under the government to form smaller populations and some became candidates for reintroduction. The total number of *R.e. siamensis* in Thailand reported in 2019 was 109 deer housed in 3 zoos, 51 deer totally, and 5 wildlife breeding centers across Thailand, 58 deer totally (ZPO 2022).

For the *R.e. thamin*, there have been reports on them being kept illegally by many private organizations in the past. However, these animals became the important source of founders for the captive breeding program of *R.e. thamin* in government facilities (Thongphakdee et al. 2018).

In 1983, the large number of *R.e. thamin* in captivity allowed reintroduction programs for this subspecies. Phu Khieo Wildlife Sanctuary (PKWS) experimented with the first Eld's deer reintroduction in Thailand (Bhumpakphan et al. 2003). Eld's deer were selected from many wildlife breeding centers to take part in a soft release program by moving 13 Thamin to a 6.4 ha enclosure covering forest and grassland for 2 years. The deer produced 3 offspring in the second year. Before releasing them, radio collars were placed on 6 deer to monitor them after release. One female died from being hunted by dholes (*Cuon alpinus*). From observation together with data from PKWS in 2002, it was found that this Eld's deer population was healthy and active evaluated based on the body condition score, mostly grazing in the grassland, near water sources and in a pine-dipterocarp forest. In 2002, a herd of 5 Eld's deer, 2 adults, 1 juvenile and 1 large fawn was seen (Bhumpakphan et al. 2003). The latest recorded sighting in August 2004 was an adolescent with its third set of antlers living alongside a herd of hog deer and sambar deer in PKWS, with 10 members (Prasanai et al. 2012).

In 2009, the reintroduction of *R.e. thamin* into Huai Kha Khaeng Wildlife Sanctuary (HKKWS) was first conducted by hard releasing 20 radio-collared deer and monitoring their progress before the actual release was recommended. Later, an additional 38 deer were released with 33 having radio collars attached (Bhumpakphan et al. 2018). Up to 2022, a total of 554 *R.e. thamin* have been reintroduced into 10 protected areas in Thailand (Figure 2). Reintroduction of *R.e. siamensis* has also been conducted in 2 areas, including Phanom Dong Rak Wildlife Sanctuary in 2018 and PKWS in 2020, with a total of 27 *R.e. siamensis* released (Office of Wildlife Conservation, 2021). Reintroduction details for both subspecies are summarized in Table 2.

In the case of captive stocks of Eld's deer were also held in India, there were 15 Sangai constituting 7 males, 7 females, and a fawn in captivity in 2018 (Singh and Khare 2018). Hartley (2018) reported that there was 155 *R.e. thamin* managed by the European Endangered Species Program. Pukazhenthi et al. (2003) reported a total of 230 *R.e. thamin* in captivity in North American, primarily distributed among 3 herds separated by as much as 4500 km. There were about 24 Eld's deer in captivity in Phnom Tamao Wildlife Rescue Centre, which originated from just two individuals (Gray et al. 2015).

PREPARATION FOR ELD'S DEER REINTRODUCTION

Habitat selection and preparation

Translocation has become a common practice in conservation programs (Taylor et al. 2017; Garnier et al. 2021). However, the programs still remain challenging and the success rates are low despite extensive planning and a considerable investment of resources. One of the factors that influence whether the released animals stay within or disperse from the designated release area is the habitat quality (Bennett et al. 2012). Therefore, habitat selection and habitat improvement are essential for a reintroduction program (McCarthy et al. 2012; Paraskevopoulou et al. 2021). Habitat preparation for the Eld's deer reintroduction

programs in Thailand was conducted using satellite image data to determine suitable habitats for the released Eld's deer (McShea et al. 2005; Stadtmann and Seddon 2020). This work was conducted based on the studies of natural Eld's deer habitats in Myanmar and Lao PDR, indicating areas of dry dipterocarp forest in the plains or areas with a height not exceeding 600 m above sea level, with an area size ranging from 30 km^2 or more to be chosen.

The detailed spatial survey process considers the dry dipterocarp forest (DDF) ecosystem and environmental factors, permanent water sources, saltlicks in the release area, as well as the ecology of forest fires (McShea et al. 2018). The release pen is prepared for holding the deer before reintroducing them into the wild. A primary survey should be performed and a project on habitat management in the dry dipterocarp forest areas should be conducted by managing the lower wood floor making the forest sparse and creating a grass source by careful control before entering the wildfire season (Sirimagone et al. 2009). Water sources must be managed for the dry season (Kamolnarranath et al. 2004).

Subspecies classification

Subspecies classification was based on the genetic differences between *R.e. siamensis* and *R.e. thamin* (Sukmak et al. 2013). There is clear management separation between the two different subspecies, using Bang La Mung Wildlife Breeding Center, which has a large area, as the breeding place of *R.e. siamensis* and the HKK Wildlife Breeding Center as the breeding ground for the Thamin subspecies (Kamolnarranath et al. 2004). For the *R.e. thamin*, the breeders were chosen from the DNP wildlife breeding centers and KKOZ under the ZPO by considering the physiognomic characteristics, individual numbering, history recording, and genetic testing to understand the heredity and kin relationships among the deer (Bhumpakphan et al. 2003). Eld's deer breeders were then moved from various DNP wildlife breeding centers to HKK Wildlife Breeding Center, Uthai Thani province (Thongphakdee et al. 2018). This would allow the building of a global herd to be the representative herd of *R.e. thamin* for future use, including reintroduction (Kamolnarranath et al. 2004).

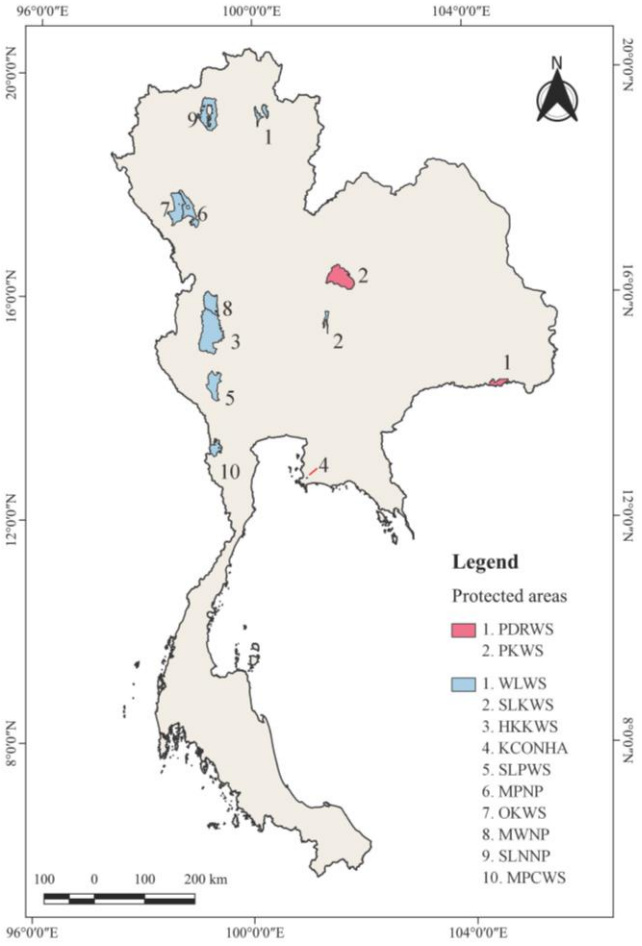

Figure 2. Map the protected areas with reintroduced *R.e. thamin* (blue areas) and *R.e. siamensis* (pink areas) from 1999 to 2022

Table 2. Number of Eld's deer reintroductions in the protected areas of Thailand following the DNP Eld's deer population restoration during 1983- 2022

Location	Year	Subspecies	Number of releases
Phanom Dong Rak Wildlife Sanctuary (PDRWS)	2018	Siamensis	20
Phu Khieo Wildlife Sanctuary (PKWS)	2020	Siamensis	7
Wiang Lor Wildlife Sanctuary (WLWS)	1999-2008	Thamin	25
Sublangka Wildlife Sanctuary (SLKWS)	2006	Thamin	9
Huai Kha Khaeng Wildlife Sanctuary (HKKWS)	2009-2022	Thamin	217
Khao Chi-on Non-Hunting Area (KCONHA)	1993	Thamin	60
Salakpra Wildlife Sanctuary (SLPWS)	2011-2018	Thamin	71
Mae Ping National Park (MPNP)	2019	Thamin	75
Omkoi Wildlife Sanctuary (OKWS)	2016-2017	Thamin	26
Mae Wong National Park (MWNP)	2017	Thamin	30
Sri Lanna National Park (SLNNP)	2019	Thamin	4
Maenam Phachi Wildlife Sanctuary (MPCWS)	2016	Thamin	15
Phu Khieo Wildlife Sanctuary (PKWS)	1983-2004	Thamin	22 (complete extirpation in 2004)
Total			581

Sources**:** Office of Wildlife Conservation (2021**)**

Husbandry practices and genetic investigation

Husbandry practices for successful keeping and breeding of Eld's deer for reintroduction should be performed (Wall and Hartley 2017). Health assessment can ensure that the deer released back into the wild will not be carriers of various diseases into the natural herd. Candidates for reintroduction should first be moved to soft-release pens to prepare them for release, which includes minimal feeding by humans and intimacy with people (Kamolnarranath et al. 2004).

Genetic management plays an important role in improving the performance of reintroduction actions (Lott et al. 2020; Willi et al. 2021). The genetic diversity and degree of inbreeding in a population are directly dependent on the effective population size, a fundamental parameter for the conservation of threatened species (Muniz et al. 2019). Several studies have evaluated that genetic consequences induced by reintroduction events for some ungulates were essential, for example, Przewalskii's wild horse (*Equus ferus*) (Liu et al. 2014; Wang et al, 2014) and Père David's deer with a population increase from 39 to over 3000 individuals between the 1980s and 2017 (Zhu et al. 2018). The genetic diversity of captive Eld's deer in Thailand has been investigated intensively to separate the 2 subspecies (Sukmak et al. 2013; Munsuwan et al. 2021). Angom et al. (2017) reported that no genetic variation was observed among the *R.e. thamin* populations, which indicates that the population has passed through the bottleneck effect that might have resulted in the inbreeding depression. Captive population management to maintain the population number at a suitable level requires genetic management or management of breeding different bloodlines to increase the genetic diversity instead of increasing the population in related bloodlines or through inbreeding, which creates a low-quality population (Thongphakdee et al. 2018).

Released method

Based on the strategic plan meeting at KKOZ in 2003, it was proposed to reintroduce experimental animals to HKKWS. These animals were tested for diseases and sterilized before release. This was done during the preparation phase while waiting for the reproduction and increase of the target population, which are candidates for future releases (Bhumpakphan et al. 2003). The post-release monitoring and reporting were conducted using radio-collaring of representative deer (Buranapim et al. 2008).

The *R.e. thamin* reintroduction was carried out using a soft release method at every site, which allowed a gradual release of wild animals by placing the deer in a holding area prepared to support the release of wildlife, to train the deer to get used to the area and gradually expand the cage area to allow more space for the deer to do more activities. Sometimes, in this case, the deer may need help by providing food and water during the dry season or protection against predators. Reintroduction programs were conducted in 12 protected areas of Thailand (Figure 2 and Table 2) (Office of Wildlife Conservation 2021). The reintroduction program in WLWS started in 1999. At that time, 8 deer were reintroduced using a soft release method, and now the Eld's deer population in WLWS has increased to 30. The area was managed by strengthening the defenses, by public relations and community education, along with by improving the habitat by tilling and making grass plots in some areas (Phuwinsaksagul et al. 2014).

Post-release monitoring

Post-release monitoring is a very useful tool to evaluate animals' fitness and further strengthen wildlife management practices (Myers and Young 2018; Mandlate et al. 2019; Khattak et al. 2020; Prosekov et al. 2020). The effective monitoring of an endangered population, and associated conservation planning, requires detailed information relating to behavioral and demographic information (Bhattarai and Kindlmann 2018). Post-release monitoring and surveys were conducted via radio telemetry, camera trap and direct observation techniques. All areas where Eld's deer were released into the wild were monitored by direct observation on a daily basis for one year after release and monitored periodically. Foraging behavior, shelter, habitat selection, birth, death, cause of death, distribution and relationship with other wildlife in the area especially hunting from carnivorous wildlife were observed and recorded. In the case of reintroduction of Eld's deer in WLWS, Sukmasuang et al. (2013) found that some released Eld's deer traveled about 40 km from the release site to feed on the agricultural crop, which was located close to the boundary of the wildlife sanctuary.

The results from monitoring using the camera trapping method in WLWS for 1 year-round after 13 years after being released within an area of about 10 km^2 that placed systemically, 500 m interval, showed that the adult sex ratio between male: female was 1: 1.38. The ratio of adult males: adult females: juveniles: fawns in the population was 11.35: 54.04: 32.32: 1.88. The ratio of adult females to fawns was 1: 0.01 (Sukmasuang et al. 2013). The periods with the highest activity were 03:00 and 16:00 (Sukmasuang et al. 2013). Behavioral studies were also performed on released adult male Eld's deer on Hainan Island, which showed that they did not shift their activity period during the rut season, but did increase the length of each activity period; the deer became more nocturnal when translocated near humans (Ding et al. 2012).

Puwinsaksagul et al. (2014) reported the distribution of released Eld's deer in WLWS and found that most of the released deer were found around the released area, which is a flat area along a creek and adjacent to the officers' residence zone. The surveys showed that most of the deer released remained in the vicinity of the holding pen and the officers' residences, nurseries and staff housing. The Eld's deer mainly used the area near the officers' residences, followed by man-made grassland, mixed deciduous forest, and dry dipterocarp forest, which indicated the released Eld's deer selected the area near humans. Currently, the suitable area for releasing Eld's deer in the protected area was found not far from the villages located near the boundary. Therefore, cooperation with the surrounding

communities to protect the released Eld's deer should be determined. Moreover, the use of toxic substances in agricultural areas near the edge of protected areas requires caution. WLWS, together with local authorities, used to support non-toxic rice farming around WLWS to reduce the impact on the released Eld's deer (Puwinsaksagul et al. 2014).

Parameters obtained from post-released monitoring were analyzed in population viability analysis (Buranapim et al. 2008). In the case of the 44 released Eld's deer in HKKWS showed 95.29% natality probability of female based on 6-month monitoring after release and also found 51.2% sexual maturity of male. The mortality rate of the released animal showed 82.35% in females and 86.67% in males. The result of the PVA showed the decline of the released population, although the program starts with an initial population of 100 individuals. Thus, the released program should reduce the mortality rate to less than 40% then the released population can self-maintain sustainably. Sex ratio between the male and female of the animal that was suitable for reintroduction program was 1:3 or 1:4 (Buranapim et al. 2008).

The Eld's deer released in HKKWS were found to spend most of their time ruminating and resting in shaded areas along the boundary between the dry dipterocarp forest and mixed deciduous forest, to hide from their natural predators (Buranapim et al. 2008).

Habitat section of released Eld's deer

Space use by animals is a key factor in animal ecology and one of its core concepts is the home range (Rühmann et al. 2019). A home range is defined as that area traversed by the individual in its normal activities of food gathering, mating and caring for the young, indicating the close relationship between animals and their environment (Powell and Mitchell 2012). In the case of reintroduced Eld's deer, knowledge about their habitat requirements and movement ecology is one of the greatest challenges in restoring species to the wild (Mertes et al. 2019). From monitoring reintroduced Eld's deer using radio tracking in HKKWS, Buranapim et al. (2008) found that the overall released Eld's deer home range calculated from all of the geographic coordinates was 36.20 km^2. The male deer had an average home range of 13.42 km^2 and that of the females was 11.00 km^2 (Buranapim et al. 2008). While the monitoring results of the 4 reintroduced Eld's deer, including 2 males and 2 females in SLPWS, Kanchanaburi province, showed that the home range size of the males was only 1.50 km^2 and 1.75 km^2 for the females. The overall home range area was 11.47 km^2. The differences in the size of home range areas of the two areas may be due to habitat differences, especially the different denseness. In HKKWS appears, the dry dipterocarp forest, while in SLPWS is a mixed deciduous and dry evergreen forest.

The home range of the reintroduced Eld's deer in SLPWS during the rainy season was larger than in the dry season (Prempree et al. 2013). Like with the sympatric species as 17 radio-collared barking deer in HKKWS showed larger home range size in the wet season than that of the dry season due to the distribution of forage species and intraspecific relationship within species (Sukmasuang 2001). The home range size of the released Eld's deer in HKKWS was similar to the 19 radio-collared wild Eld's deer in the Chattin Wildlife Sanctuary, Myanmar, which had an average size of 9.04. km^2 (Aung et al. 2001) and was larger than the home range size of the 17 radio-collared Hainan's Eld's deer that had an average size of 7.25 km^2 (Pan et al. 2014).

FOOD PLANT SPECIES

Eld's deer are grazers, similar to cattle and buffaloes. Apart from grasses, they also like to eat various types of wild fruit found in grasslands or sparse forests. They do not like to take many leaves to eat at once like browsers (Gray et al. 2015). Based on direct observation after location tracking from radio signals of the released Eld's deer in HKKWS, found a total of 16 plant species could be found in DDF, along streams and in grassland, including the young shoots and leaves of wild plants (Buranapim et al. 2008). Aung et al. (2001) studied the feeding behavior of the Eld's deer at Chatthin Wildlife Sanctuary in central Myanmar and found that they like to graze on young grass and some agricultural plants, as well as 8 species of fruits that are commonly found in the area. Twenty forage species were identified for both Eld's deer. The mean annual biomass of these forage species of the Eld's deer was 2764.26 g m^{-2} (Tuboi and Hussain 2014).

List of forage species of released Eld's deer into nature showed that the number of forage species varies according to the study site such as Zhang et al. (2019) reported 234 species of plants, including 161 herbaceous herbs, 71 ligneous plants and 2 ferns are eaten by Eld's deer in Hainan Island along with the 10 favored plant species (Sun et al. 2009).

From the study of food plant species in WLWS, a total of 126 species of plants were seen to be eaten by the deer. The plants eaten were trees (41 species), followed by shrubs (25 species), herbaceous plants (30 species), grasses (7 species), vines (19 species), ferns (2 species) and bamboo (1 species). In the dry season, a total of 107 species of plants were surveyed and in the rainy season, 88 species were recorded (Puwinsaksagul et al. 2014). The data review of the food plant species of Siamese Eld's deer revealed that 16 plant species were found in Bang La Mung Wildlife Breeding Center (Poolpon 2006), 16 species in HKKWS (Buranapim et al. 2008), and 26 species in SLPWS (Prempree et al. 2013). The most forage species that were fed by the released Eld's deer in SLPWS were Fabaceae family such as *Dicerma biarticulatum*, *Albizia odoratissima*, *Millettia brandisiana*, *Bauhinia variegata*, etc.

THREATS AND CONSERVATION INTERVENTIONS

In Thailand, the protected area system failed to prevent the species' effective national extinction some years ago (Gray et al. 2015). It seemed that this happened everywhere the population remains in nature. Khant et al. (2018)

reported the number of *R.e. thamin* in Chatthin Wildlife Sanctuary (CWS), Myanmar, had been decreasing gradually. Furthermore, illegal hunting was yet to be addressed, as well as the pressure from various human disturbances in the area. In the case of the hard released Eld's deer in HKKWS, based on a 24-week follow-up, the base population was 44 individuals, the percentage of male Eld's deer in the reproductive age group was 51.20%, the percentage of female Eld's deer mortality was 82.35%, and the mortality of male Eld's deer was 86.67% (Buranapim et al. 2008). Cases of death in the released population in HKKWS and SLPWS came from leopards, tigers, dholes (Charaspet et al. 2020) and pythons. Cases of death of released Eld's deer in SLPWS came from the transportation processes (Prempree et al. 2013). The survival rate of the released Eld's deer was 15.63%. The male survival rate in HKKWS was 13.33% from 15 male deer and the female survival rate was 17.65% from 17 females (Buranapim et al. 2008). In SLPWS, one male and one female Eld's deer died in pen or 33.33% of the total number (Prempree et al. 2013). Released Eld's deer may be harmed by both domestic dogs and toxins used in the agricultural area when go out from the released site to roam in agricultural crops, as happened in SLPWS, WLWS and HKKWS, which is a threat that must be considered to be solved.

In the past, poaching in protected areas in Thailand was severe (Jenks et al. 2012). Enforcement of wildlife laws is one of the greatest determinants of megafauna persistence and recovery (Aryal et al. 2017; Figel et al. 2021). Ranger patrols, which generally rely on deterrence to motivate compliance, have been the major focus of anti-poaching strategies (Duangchantrasiri et al. 2016; Risdianto et al. 2016). In Thailand, for example, intensive patrolling from 2005 to 2012 significantly reduced poaching, thereby enabling the increase of the tiger population in HKKWS (Duangchantrasiri et al. 2016). However, campaigning to reduce demand may be more cost-effective than anti-poaching enforcement (Holden et al. 2018; Salazar et al. 2018). The intensity of patrols has reduced poaching incidents over the past decade, which still needs to be done on an ongoing basis in Thailand. The importance of collaborative anti-poaching strategies was supported by the consistently documented inverse relationship between hunting pressures and proximities to human settlement (Tilker et al. 2017; Mudumba et al. 2020), which are important conservation and restoration issues for wild species, including Eld's deer.

CONCLUDING REMARKS

In conclusion, Eld's deer are listed as endangered in the world. They had extinct from the wild of Thailand. Although Thailand used to be the center of distribution of this species showing the abundance in the past. Efforts are being made to restore the Eld's deer population to enhance conservation status and to conserve the natural population and the integrity of the respective ecosystems by releasing them back into nature. The process of restoring this wildlife population in Thailand has been scrutinized in a comprehensive review of information related to filling the gaps of knowledge for the conservation and restoration of this wildlife species to be successful. The first release of 7 Eld's deer was held in PKWS in 1982.

The Eld's deer reintroduction program in Thailand started again during 1992-1994. There was a break in the project due to policy uncertainty until 2003. In 2004, a pilot project of a hard release in HKKWS was conducted. After that, the deer were gradually released adding to a total of 44 deer, with 33 deer radio-collared. However, it was found that the survival rate was low. Until now, 554 *R.e. thamin* have been released in 12 protected areas of Thailand and 27 *R.e. siamensis* have also been released back into the wild. The main problem of Eld's deer conservation is the loss of vast flat areas in the DDF. Recommendations for species conservation are as follows: Eld's deer breeding for reintroduction programs must be carried out under the guidelines of IUCN/SSC (2013); Seddon et al. (2014); Batson et al. (2015). The genetic manipulation of both the *R.e. siamensis* and *R.e. thamin* in captivity (Sukmak et al. 2013) can serve as a basis for reintroduction planning. The target areas of population reintroduction must be clearly defined (McShea et al. 2004, 2005) and continual improvement undertaken (Sirimagorn et al. 2009), especially in a protected area, to ensure strict preservation of the remaining habitat without interference with the mechanism of wildlife conservation law (Suksawang 2018; Singh et al. 2021). The approach of Eld's deer restoration proposed to be used includes the process of preparing the site, releasing, post-release monitoring, transportation, and preparing evaluation reports which should all be improved.

Research should be supported at various stages of breeding care (Phraluk et al. 2014) and genetic diversity (Valente et al. 2017), on an ongoing basis. PVA is an effective tool to assess the fates of populations under various scenarios of the deterministic forces and chance events (Hernandez-Camacho and Trites 2018; Kimanzi 2018; Brook et al. 2019; Blazquez et al. 2020; Fryxell et al. 2020; He et al. 2020) was recommended by Zhang et al. (2021b) and should be considered in the Eld's deer reintroduction program both for Eld's deer in captive and that released into the wild (Buranapim et al. 2008). That may differ in each area to determine the parameters that affect the viability of the population in each area as well as planning for population preparation in captivity on the basis of appropriate information. Although Thailand's Eld's deer rehabilitation activities have been ongoing intensively for nearly 3 decades, nevertheless, rather few academic reports have been produced. The effective population size in the release sites that can maintain viability for the long-term should be investigated and also effective population size in captivities that can maintain genetic diversity and natural behavior in preparation for release into the wild that can maintain self-population using PVA requires continuous study. Post-release monitoring of the released Eld's deer on the ecology and threats to facilitate effective conservation planning and management should be conducted to find the recent trends in the population dynamics and to understand habitat selection, diet food items and threat factors is required intensively

and continuously to improve the whole process under the PVA to identify key knowledge gaps. In some cases, precautions for the use of toxic substances in agricultural areas near release sites should be determined for released Eld's deer, especially the released site that do not know far enough from the boundary and agricultural area because the released animals frequently find themselves in areas near human activities where they should be cautious (Merkle et al. 2018; Hughey et al. 2021).

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