Octa Journal of Environmental Research ***April - June, 2013***
International peer-reviewed journal ISSN 2321-3655
Oct. Jour. Env. Res. Vol. 1(2): 65-76
Available online http://www.sciencebeingjournal.com

Review Article

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

A REVIEW ON GENETIC STATUS OF ELD'S DEER *RUCERVUS ELDII*: WITH NOTES ON DISTRIBUTION, POPULATION STATUS AND FUTURE PERSPECTIVES

Sangeeta Angom[a] and Syed Ainul Hussain[b]*
a,b. Wildlie Institute of India, Dehradun – 248 001, Uttarakhand, India
*Corresponding author's Email: hussain@wii.gov.in

Received: 11th March, 2013 Revised: 27th May 2013 Accepted: 15th June 2013

Abstract: The Eld's deer *Rucervus eldii* once distributed throughout Southeast Asia extending from northeast India to Indochina and southern China is now confined to small fragmented areas. Four subspecies were identified; *R. e. eldii* in Manipur, India, *R. e. thamin* in central plains of Myanmar and western Thailand *R. e. siamensis* in Lao PDR and in the northern and eastern Cambodia and a fourth subspecies *R. e. hainanus* in Hainan's Island China. The review revealed few molecular investigations have been conducted on the genetics of Eld's deer based on karyotype analysis, mtDNA and microsatellites. Studies based on mtDNA control region have shown that population of *R. e. eldii* showed closest relationship with *R. e. thamin* than to *R. e. siamensis*. Microsatellites studies are limited to *R. e. hainanus*; the genetic variability was low suggesting that founder effects and genetic drift have affected the population. There still remain many knowledge gaps in the systematic and genetic status of this species. The population of Eld's deer suggested ≈2165 individuals by 2003 spreading over nine reserves. Population sizes of most subspecies of Eld's deer are small and threatened due to effects of inbreeding depression, loss of genetic variability and drift. Environmental fluctuations due to variation in predation, competition, disease, poaching, habitat deterioration and natural catastrophes are some of the other reasons affecting the population. In future, more research is required to determine the genetic population structure on the basis of markers, variable enough to detect differences between the subspecies. An extensive study is required to assess the relatedness and kinships among captive and wild population so that changes in genetic variability could be identified and appropriate conservation measures are taken. Genetic monitoring of both the source and reintroduced populations should be done prior to reintroduction in order to assess effectiveness of conservation program.

Keywords: Conservation genetics, Distribution, Eld's deer, Population status, Systematics

Postal Address: Syed Ainul Hussain, Wildlife Institute of India, Post Box # 18, Chandrabani, Dehra Dun - 248001, Uttarakhand, India. Phone: +91-135-2640111-115

INTRODUCTION

The family Cervidae includes 40 species of deer distributed throughout the northern hemisphere, as well as in South America and Southeast Asia (Gilbert, 2006). Of the seventeen species of cervids occurring in Southern Asia and far East, seven species *viz.* Muntjac *Muntiacus muntjak* , Sambar *Rusa unicolor*, Chital *Axis axis*, Hog deer *Axis porcinus*, Swamp deer *Rucervus duvaucelii,* Hangul or Kashmir stag *Cervus elaphus* and Manipur Eld's deer *Rucervus eldii* occur in India

(Whitehead, 1993). Among these, the Eld's deer or brow-antlered deer *R. eldii* is one of the most endangered species of the deer found in South and Southeast Asia. The majorities of the present day Eld's deer population have either recovered from severe demographic bottlenecks, or are living in fragmented, isolated and small population of the Northeast India, Myanmar, Cambodia, Laos, Vietnam and Southern China (Hussain et al., 2006; Timmins and Duckworth, 2008).

The population sizes of most threatened species are small. The effects of inbreeding are of concern with such small population sizes (Soulé, 1980). Genetic variability is thought to be essential for the long term persistence and adaptability of populations, and thus the management of captive and wild populations of endangered species should minimize the loss of genetic variability. Both morphological and molecular techniques can be used to compare variability between populations and to follow the decline of variability in small populations (Wayne, 1991). Molecular genetic markers are powerful tools in identifying the genetic uniqueness of an individual's population or species (Avise, 1994; Linda and Paul, 1995). Reduction of genetic variability in a small population can minimize the ability of a species to cope with the adverse environmental conditions, reduced population density and in some cases, lead to the extinction of the species. Extinction of the species is directly related to the reduction of genetic variability which is a crucial factor both for short term fitness of individuals and long term survival of the species (Primack, 1993).

DNA based studies have been of great interest in the conservation biology of endangered species and in the population genetics of cervids (Avise, 1994). Molecular genetic markers such as mtDNA (control region) and nuclear microsatellites are used in estimating the genetic diversity and effective population size, identifying the genetic uniqueness of an individual's population or species, understanding gene flow patterns among populations, determining parentage, linkage mapping and determining relationships among individuals in a population (Primack, 1993; Avise, 2004).

Our goal is to review the up-to-date published studies on population genetics of Eld's deer with special emphasis on karyotypic composition, phylogenetic relationship and population characteristics. For each subspecies of Eld's deer, systematic, distribution and population status were reviewed based on the literature and published records. Data on past distribution and population status were presented in tabular form and summarized based on published studies. The distribution ranges of each subspecies were plotted using the GIS software Arc View 3.2.

CONSERVATION GENETICS

The Eld's deer population being small and highly fragmented is subject to a higher chance of extinction because they are more vulnerable to inbreeding depression and genetic drift, resulting in stochastic variation in their gene pool, their demography and their environment. In addition, the long term viability of small populations can impact on population persistence *viz.* lower the fecundity and survival of inbred individuals within a population, will depress population growth rate, which in turn has contributed to accelerated rates of extinction and reduction in genetic load. Very few investigations have been conducted on the genetics of Eld's deer in the wild based on karyotype analysis, mitochondrial DNA genes and microsatellite loci. Molecular phylogenetic studies based on mitochondrial DNA (Miyamoto et al., 1990, Randi et al., 2001, Cook et al., 1999, Polziehn and Strobeck, 2002, Ludt et al., 2004) and nuclear DNA (Comincini et al., 1996) sequence comparisons have contributed considerably to resolving evolutionary relationships among deer species at the family level (Cervidae), but these studies have not fully resolved the phylogeny of the Cervinae because they lacked material from many of the extant Old World deer species. The maternal ancestry of *E. davidianus* is proto- *R. eldii*, from its stems. This unites Pére David's deer (*E. davidianus*) with the tropical Southeast Asian Eld's deer (*R. e. thamin* and *R. e. hainanus*) which have in the past almost invariably been associated with *R. duvaucelii* in a genus or subgenus *Rucervus* (Ellerman and

Morrison-Scott, 1951). Its paternal ancestor would then be the species ancestral to the rest of the genus *Cervus*. Nagata et al., (1999), using the D-loop, and Cook et al., (1999), using cyt b, studied the sika population from China and showed that the northern Japanese sika and the southern form actually form three equal branches. The northern form of the Japanese sika is much larger than the southern form their sizes barely overlap. Thevenon et al., (2000) studied the karyotype identity of two Eld's deer subspecies, *R. e. siamensis* and *R. e. Thamin*. Their findings showed no chromosomal differences at the subspecies level. This finding suggested that at least from a karyotypic perspective no obvious differences delimit the two subspecies, and hybridization between *R. e. siamensis* and *R. e. thamin* is not likely to lead to impaired fertility in hybrid animals. On similar lines, Tanomtong et al., (2008) studied the cytogenetics of *R. e. siamensis* of Thailand and *R. e. thamin* of Myanmar and showed that these two subspecies exhibit the same karyotype, with a diploid number of 2n=58 (fundamental number, NF=70) for females and 2n=58 (fundamental number, NF=71) for males.

Pitra et al., (2004) used mitochondrial cytochrome b sequences to assess the phylogenetic pattern and timing of radiation of Old World deer in 33 Cervini taxa. The major findings were that the genera/subgenera *Axis, Rucervus* and *Rusa* and the species *C. elaphus* are non-monophyletic and that *Elaphurus davidianus* belongs to genus *Cervus*. Of the species referred to *Rucervus*, two (*R. duvaucelii* and *R. schomburgki*) form a clade which is only remotely related to other Cervini but may be distantly linked to *A. axis*, while the third (*R. eldii*) is closely related to *Cervus* and linked to *E*. *davidianus*. A recent phylogenetic study placed Eld's deer as the sister taxon to another swamp adapted species, Pére David's deer (*E. davidianus*), and these two species constituted the basal lineage in the *Cervus* clade (Randi et al*.,* 2001). Balakrishnan et al*.* (2003) analysed the variation in the mtDNA (control region) of the three subspecies of Eld's deer and showed that the ecologically divergent *R. e. eldii* is related more closely to *thamin* than to *siamensis*. The study showed that *R. e. thamin* and *R. e. siamensis* are distinct subspecies, but *R. e. hainanus* is characterized by a unique and relatively divergent mtDNA haplotype, suggesting duration of historical isolation. A strong degree of phylogeographic structure both between subspecies and among populations within subspecies is also indicated, suggesting that the dispersal of individuals between populations has been very limited historically. The haplotype diversity was relatively high for *thamin* and *siamensis*, indicating that the recent population decline has not yet eroded the genetic diversity, whereas no haplotype variation was found within the *R. e. eldii* and *R. e. hainanus* populations, which are known to have suffered population bottlenecks. Pang et al*.* (2003) found no genetic variability using mtDNA control region genes in *R. e. hainanus*, which has suffered recent population contractions. Their study employed a simulation approach to test the likelihood of various bottleneck scenarios and showed, in the context of what is known about the recent demographic history of this population, that there are credible scenarios for a bottleneck driven by hunting pressures in the 1960s.

Guha and Kashyap (2005) examined the mitochondrial 16S rRNA gene for identification of blackbuck, goral, nilgai, hog deer, chital, sambar and Myanmar's Eld's deer. The heminested PCR assays designed by them were successfully validated for sensitivity and specificity and provide a reproducible and rugged method allowing analysis of low copy number DNA recovered from decomposed or highly processed tissues under a wide range of conditions. Guha et al. (2007) analysed two mitochondrial genes, 16S rRNA and cytochrome b, to resolve the phylogenetic position of the pecoran species, i.e., species of the families Bovidae, Cervidae and Moschidae endemic to the Indian subcontinent. The results established the basal position of the family Tragulidae and the monophyly of the infra-order Pecora within the suborder Ruminantia and demonstrated that the families Bovidae, Cervidae and Moschidae are allied to the musk deer *Moschus chrysogaster* showing that this species is more closely related to bovids than to cervids.

Molecular studies employing microsatellite DNA loci were limited to *R. e. hainanus*. Zhang et al. (2005) characterized 10 polymorphic microsatellite markers for Hainan's Eld's deer. Their results showed that these markers should be suitable for conducting population genetic studies on Eld's deer and possibly other ungulates. Zhang et al. (2008a) assessed the genetic variability in the one source (Datian Reserve) and two introduced populations of *R. e. hainanus* (Bangxi and Ganshiling Reserve). They found that the genetic variability was low in each of the three populations and suggested that founder effects and genetic drift had affected the two translocated populations. They recommended that the three populations be managed as a meta-population for conservation. Zhang et al. (2005; 2008b) studied the isolation and characterization polymorphic microsatellite markers for *R. e. hainanus* and showed that these markers provide a useful tool for conducting population genetic studies on Eld's deer and possibly other ungulates. Song (1996) used the program VORTEX to determine the essential requirements for the long term conservation of two isolated deer populations of Hainan's Eld's deer. The results indicated that both groups are susceptible to extinction, given demographic challenges or environmental variations. At the same time, separating the groups reduced the population sizes, which could have led to further losses in genetic variability. Since 1995, the two isolated groups have been merged into an intact population again. In the future, more research is required to determine the genetic population structure on the basis of genetic markers, variable enough to detect differences between all the three subspecies of Eld's deer (an extensive study of microsatellite loci). An extensive study is required to assess the relatedness and kinships among all the captive population of sangai to determine the genetic population structure of each population/sub population so that changes in genetic variability due to inbreeding depression and founder events in the populations could be identified and appropriate conservation measures are taken. Genetic monitoring of both the source and the reintroduced populations should be done prior to reintroduction in order to assess the effectiveness of the conservation program.

CONSERVATION STATUS

Eld's deer is listed as "Endangered" in the IUCN Red List (Timmins and Duckworth, 2008) based on estimated rates of decline which averaged across the species, exceed 50% in three generations (Timmins and Duckworth, 2008), and in Appendix I of the Convention on International Trade in Endangered Species (CITES). In India, the species is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972. After its rediscovery on the southern fringes of Loktak Lake, in Manipur, the area was declared as a protected area (1954) and subsequently as a National Park (1977). The State government of Manipur recognized it as the State animal in 1989. With concerted efforts, its population is showing an increasing trend (Hussain et al*.,* 2006).

In Myanmar, the Shwesettaw and Chatthin Wildlife Sanctuaries were established in 1986 for conserving *R. e. thamin*, although a significant numbers were found outside these areas (McShea et al*.,* 2005; Tordoff et al., 2005). The species receives nationwide protection from hunting under the 1936 Burmese Wildlife Protection Act. It is one of the 15 species listed in the Wild Animals Preservation and Protection Act, 1992 as National reserved species. In spite of such efforts, the species is showing a continuous declining trend largely due to hunting and deterioration of its habitat (McShea et al*.,* 2001). The Royal Government of Thailand designated it as a national reserved species, and it is protected by the Thai Wildlife Law since 1960 (Blower, 1983).

In the Lao PDR, it is listed as Threatened and At Risk (Timmins and Duckworth, 2008). In Chonnabuly district, where it occurs in an area of 93,000 ha was formally designated as a protected area. In Cambodia, where it was previously thought to be extinct but was recently rediscovered in the northwestern part of the country (Owen, 2009), it is listed as a protected species. One or two small and isolated populations have also been identified in the Lao PDR in 2002 (Johnson et al*.,* 2004). In Vietnam, it is listed as Endangered in the Red Data Book and is also listed in Group IB of the

government's directives, which strictly bans its hunting and use (Dang and Nguyen, undated). It is also regarded as a Rank I key species in Wild Animal Protection Law of China ensuring afforded national protection (Liu, 1998).

DISTRIBUTION

The Eld's deer is limited to the tropical and subtropical region (93°06'–110°35'E, 11°10'–25°41'N) of Asia. It is largely restricted to the Irrawaddy and lower Mekong valleys between Thailand and Cambodia, with an isolated small population in the west in Manipur and lower to the south in the east in Hainan Island, southern China (McShea et al*.,* 2001). Eld's deer is believed to have originated via a land bridge from the Southeast Asian mainland and arrived in the Island of Java and Hainan during the end of Pleistocene and early Holocene (18,000-8,500 years BP) when the sea level went down below 85 m from the present mean sea level (Ginsburg et al*.,* 1982; Bhumpakphan et al*.,* 2004). Although the primary forest type of most Eld's deer populations is dry dipterocarp forest (McShea et al*.,* 2005) the fringe populations of this species occupy wetter ecosystems. Hainan's population is found in the tropical moist island in shrub forest (Zeng et al*.,* 2005). Isolated populations of *R. e. siamensis*, both in southern Laos (Round, 1998) and in Ang Trapeang Thmor Reservoir in north western Cambodia inhabit marshy areas in conditions similar to those described by Lekagul and McNeely (1977) in relation to extirpated deer in Thailand.

Eld's deer show variability in their habitat preferences. *R. e. eldii* inhabits low lying swamps (Lekagul and McNeely, 1977) and is especially adapted to the unique *phumdi* habitat. It has divided hooves, and its pasterns are greatly elongated unlike those of other deer species (Gee, 1960). Therefore, the species is especially adapted to walking conveniently over the quaking surface of Keibul Lamjao National Park (KLNP) (Singh, 1992). It naturally occurs in low densities by virtue of the limited availability of its habitat which is characterized by the swampy flood plains of KLNP, Manipur. In contrast, *R. e. thamin* and *R. e. siamensis* are found mostly in dry deciduous dipterocarp forests with an open under storey (Salter and Sayer, 1986). Evidence from Thailand and Cambodia indicates that *R. e. siamensis* is primarily associated with dry dipterocarp forests, open canopy woodlands characterized by deciduous trees and a grassland under storey (Koy et al., 2005) which are found mostly in the monsoon areas of the Mekong plains. It favours open canopies with a grass under storey or grasslands having hydrological origins. However, Lekagul and McNeely, (1977) proposed that Eld's deer originally inhabited swampy areas but were forced recently into drier habitats due to pressures imposed by hunting and the expansion of agricultural areas. There is however no evidence to suggest that Eld's deer is wetland associated. A long term research programme on *R. e. thamin* in Myanmar concluded that Eld's deer are not dependent on water sources (McShea et al*.,* 1999).

R. e. hainanus inhabits tropical plains and hills less than 200 m high with predominant scrubland and grassland with sparse trees (Xu et al., 1983). Historical records suggest its occurrence Qionghai or Qiongzhou, Chengmai, Qiongshan, Lehui, Dingan, Yazhou, Lingshui, Wanzhou) and Lingao as well as Qiongzhong (Xu and Liu, 1974; Yu et al., 1984; Yuan, et al., 2001). In the early 1950s the species used to occur in 200-300 km^2 covering 20 districts in six counties. However, by 1950s the species was disappeared from these sites.

SYSTEMATICS

The Eld's deer was first described in 1839 from Manipur Valley, India, and named as *Cervus frontalis*. Subsequently it was renamed *C. eldi eldi* by McClelland (1841) after its discoverer, Captain Percy Eld. Later, McClelland (1842) renamed it *Cervus* (*Rusa*) *frontalis*. Thomas (1918), placed it under the genus *Rucervus* thereby aligning it with the swamp deer (*R. duvaucelii*), which has a close taxonomic relationship with the extinct Shomburgk's deer, *R. schomburgki* (Corbet and Hill, 1992). Historically, three subspecies were recognized (Figure 1), namely *R. e. eldii*, *R. e. thamin* and *R. e.*

siamensis (Gee, 1960; McShea et al., 2001; Balakrishnan et al., 2003; Johnson et al., 2004; Tordoff et al., 2005). A recently recognized fourth subspecies, found in Hainan Island off southern China, was named *Cervus eldii hainanus* by Xu et al., (1983). The *thamin* deer found in the upper and central parts of Myanmar were named *R. thamin brucei* and *R. e. thamin* respectively by Lydekker and Dollman (1985).These names were assigned according to the morphology of the antlers which are slightly palmate. The *thamin* deer of westernmost and upper Thailand near the Myanmar border was described as *Panolia platyceros* by Gray (Lydekker and Dollman, 1985). Later, it was considered to represent a race of *R. eldii* and subsequently recognized as a distinct species called *R. platyceros* (Thomas, 1918). Pocock (1943) revived the generic name *Panolia* for *Rucervus* and preferred to combine all three subspecies into a single species. The study conducted by Pitra et al., (2004) using mtDNA (cyt *b*) of several deer taxa demonstrated that placement of Eld's deer in *Cervus* had been in fact phylogenetically more appropriate. However, Groves (2006) opined that Eld's deer did not belong to the genus *Rucervus* and pointed out that under the phylogenetic species concept the three taxa are extremely different as the differences between *R. e. siamensis* and the other two subspecies, *R. e. eldii* and *R. e. thamin* are prominent. Groves (2006) suggested that the taxon *siamensis* should be recognized distinct from *R. eldii* and urged that a formal study be carried out. However, Grubb (2005) revived Thomas (1918) assignment of the species to *Rucervus*. Subsequently, Wilson and Reeder (2005) accepted this and used the name *R. eldii* for Eld's deer, and this name was adopted by the IUCN Species Survival Commission (Timmins and Duckworth, 2008). The species name is often misspelled *eldi*, but the correct original spelling, which must be used, is *eldii* (Timmins and Duckworth, 2008).

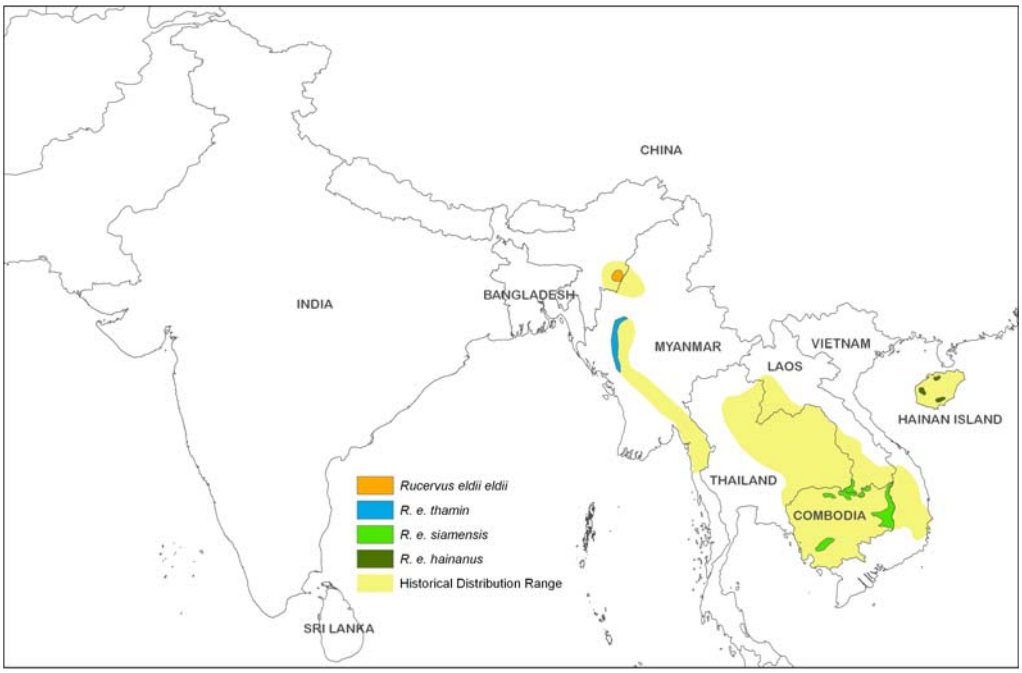

Figure 1. Present and historical distribution range of four subspecies of Eld's deer in Southeast Asia

POPULATION STATUS

In recent years the historical range of the Eld's deer has been broken into four major parts. In Manipur, the *R. e. eldii* once thought to be extinct was rediscovered in 1953 by Edward Pritchard Gee (Gee, 1960). In 1959, six individuals were counted leading to the beginning of intensive conservation efforts. Subsequently, Gee (1961) estimated the total population of Eld's deer in Manipur as 100–112 individuals. The area was subsequently protected as a National Park. The first aerial census carried out in the park, in 1975, recorded the presence of only 14 individuals (Ranjitsinh, 1975). The first ground census conducted in 1984 yield an estimate of 51 sangai, including 20 stags, 25 hinds and 6 fawns

(Shamungou, 1997).The population of sangai had increased to around 180 individuals by 2003, consisting of 65 stags, 74 hinds and 41 fawns (Singsit, 2003; Hussain et al*.,* 2006) (Table 1).

R. e. thamin has the largest population; however, it is showing a declining trend. The *R. e. thamin* conservation programme was relatively successful, with the species breeding in Zoos and being reintroduced into the wild later at two Wildlife Sanctuaries, the Shwesettaw and Chatthin Wildlife Sanctuaries. Censuses conducted in the past indicated that there were around 2,200 individuals in Chatthin Wildlife Sanctuary (Salter and Sayer, 1986). The *R. e. thamin* population in Shwesettaw Wildlife Sanctuary is estimated to have a minimum of 240 individuals (FAO, 1982). Regular transect surveys conducted in Chatthin Wildlife Sanctuary between 1983 and 1996 indicated a population decline of more than 40% (McShea et al*.,* 2001), with the population estimated at about 500 *R. e. thamin* individuals. The captive *thamin* population at Khao Khiew Open Zoo in Chon Buri, Thailand, originated from 11 founders in 1983. This captive population has increased from 98 individuals in 1996 to 200 *thamin* in 2003 (Singhasenee, 1996).

Thailand is the geographical centre of the distribution range of Eld's deer (Ginsburg et al*.,* 1982). The oldest record in Thailand is the one reported by Ginsburg et al*.,* (1982): fossil remains of teeth belonging to many carnivores, primates, ungulates and Eld's deer, from 350,000 to 8,000 years old, were found within Quaternary reddish clay deposits (from the later part of the Middle Pleistocene) at Wiman Nakin Limestone Cave in Kon San district, Chaiyaphum Province, in northeastern Thailand (Tougard et al., 1996). A fossil form of Eld's deer, from ca. 3,000 years BP was found in Java, Indonesia (Corbet and Hill, 1992). Before the Second World War, *R. e. siamensis* occurred throughout the upper northern part of Thailand; presently, it is found in the lowland forest of Dong Khanthung, Champasak Province (Round, 1998), and in Chonbuly district, Savannakhet Province (Vongkhamheng and Phirasak, 2002). Recent sightings of the subspecies have been concentrated at the trans-boundary area of the Phanom Dong Rek Range. In 1995, a small herd was seen at the Lao PDR–Thailand trans-boundary area, in Yot Dom Wildlife Sanctuary in Ubon Ratchathani Province and at the border. A herd was also reported from near Chong Pong Daeng Border Pass of Phu Jong–Na Yoi National Park in Ubon Ratchathani Province, Thailand (Kotmongkhon, 1997).

Table 1. Population status of four subspecies of Eld's deer from recent available records

Sub species	Distribution	Estimated population	Year	Source
R. e. eldii	Keibul Lamjao National Park	180	2003	Singsit, 2003 Hussain et al., 2006
R. e. thamin	Chatthin Wildlife Sanctuary	500	1996	McShea et al., 2000
	Shwesettaw Wildlife Sanctuary	240	1996	McShea et al., 2000
R. e. siamensis	Lao PDR	100	2004	Johnson et al., 2004
	Champasak Province, Northwestern Cambodia	10-12	1998	Round, 1998
	Chonbuly District , Thailand	20-30	2002	Vongkhamheng and Phirasak, 2002, Arlyne et al., 2003
R. e. hainanus	Datian Nature Reserve	1000	2003	Zeng et al., 2005
	Bangxi Nature Reserve	115	2002	Zeng et al., 2005

The *R. e. siamensis* occurs in one or two small localized populations in the Lao PDR (Johnson et al*.,* 2004) and scattered small subpopulations in the northern and eastern lowlands of Cambodia (Tordoff et al*.,* 2005). The subspecies *siamensis* of eastern Thailand is possibly extinct in the wild (Khan et al*.,* 1992). A captive population of *R. e. siamensis* maintained at the Paris Zoo since 1937 was founded with only five individuals and has never been supplemented with individuals other populations (Thevenon et al*.,* 2000). In the Lao PDR, historically, *siamensis* ranged across the Mekong lowlands in dry dipterocarp forests from Vientiane to Champasak Province on the Cambodian border (Arlyne et al*.,* 2003). At present, 5,566 km^2 of suitable Eld's deer habitat remains and it is fragmented into 51 patches with a mean patch size of 109 km^2 (McShea et al., 2001). Round (1998) found deer signs (n=6) in one of these patches near the villages of Kadan and Kadian villages and estimated that 10–12 deer remained in the area. The isolated populations of *R. e. siamensis* in southern Laos (Round, 1998) and Ang Trapeang Thmor (ATT) Reservoir in northwestern Cambodia (Owen, 2009) inhabit marshy areas similar to those in Thailand described by Lekagul and McNeely (1977). Lekagul and McNeely (1988) suggest that the predisposition of stags to wallow in mud indicates that the current distribution of Eld's deer is a result of agricultural expansion and hunting and that the historic distribution included moister dipterocarp forests and grasslands.

The current status of *R. e. siamensis* in Indo-China is largely unknown, although it is thought that small scattered herds may still remain there (McShea et al*.,* 1999). In 2002, a second population of *siamensis* was reported by the Department of Forestry from a 200 km^2 area in Chonbuly district (McShea, 2002). Deer track and sign surveys in June 2002 found 2.61 signs/km, and one individual was observed. It was estimated that potentially 20–30 deer were present (Vongkhamheng and Phirasak, 2002; Arlyne et al., 2003). The Wildlife Conservation Society has recorded sightings of *R. e. siamensis* made during community patrols in ATT since 2005. However, no systematic survey of these deer has been conducted. The seasonal nature of dipterocarp forests and the availability of permanent water sources may be significant for the density of animals that can be supported (Timmins and Duckworth, 2008). McShea et al., (2001) identified four factors explaining the presence of the deer in Cambodia's Northern Plains, including the extent of the wetlands. In Vietnam, small herds of *R. e. siamensis* have been reported from the A Yun Pa and Chu Prong areas of Gia Lai Province, Yok Don National Park of Dak Lak Province and Yok Don NP Chu Mom Ray Nature Reserve of Kon Tum Province. However, their exact status is not known (Timmins and Duckworth, 2008). So far, 19 protected areas have been established or proposed in the distribution range of Eld's deer in Vietnam. The species has been recorded in five of these protected areas recently (Dang and Nguyen, undated).

The *R. e. hainanus* consisting of populations in Hainan Island and mainland southern China appears to have been made up of disjunct outliers of *R. e. siamensis*, separated from the main range by mountainous terrain in the Lao PDR and Vietnam (Xu et al*.,* 1983; Timmins and Duckworth, 2008). The population size of *R. e. hainanus* in the central and western regions of Hainan Island was estimated at more than 500 individuals in the 1950s (Liu, 1998). However, following severe exploitation, commercial hunting and a rapid increase in the human population and expansion of agricultural lands, the extent of the habitats was continually reduced (Song, 1993). This subspecies suffered a major range contraction and was considered almost extinct by the early 1970s (Song, 1996; Liu, 1998). The Datian Nature Reserve, where the last 26 survivors were found, was established in 1976 (Song and Li, 1992). Subsequently, the relict population has recovered slowly, although it has continued to experience sporadic poaching and habitat degradation (Song and Li, 1992; 1995; Song, 1996). The population was once on the verge of extinction, with only two isolated groups with a total of 46 deer were recorded in 1976 in Datian Nature Reserve (DNR) and Dongfang and Bangxi Nature Reserve Baisha (BNR) (Song, 1996). After the deer at BNR were finally wiped out by poachers in 1981, DNR and its vicinity became a unique site, harbouring the last group of Hainan Eld's deer (Yu et al., 1984). The population at DNR increased to 75 individuals in 1983 and to 375 in 1993, with an average annual

growth rate of 17.46% since 1983 (Zeng et al., 2005). Unfortunately, the population of Hainan declined to 342 in 1994 due to a food shortage caused by a serious drought that year and by the high density of (87 deer/km^2) within the enclosure with an area of only 3 km^2. Since DNR was entirely enclosed, the deer population has increased again, with an annual growth rate of 16.70% on average between 1994 and 2000. By 2000, the population size had reached 864 individuals (Yuan et al., 2001). It was estimated that there were over 1,000 deer at DNR in 2003 (Zeng et al., 2005). In 2002, after a reintroduction, the population of Hainan's Eld's deer at BNR increased to around 115 individuals (Zeng et al., 2005).

CONCLUSION

Studies on the ecological and genetic profiles of Eld's deer are still in their infancy compared with the detailed work and conservation efforts carried out with other cervids elsewhere in the world. The relocation and reintroduction efforts need to be carried out after careful ecological examination of the sites along with long term scientific research and monitoring. The species needs to be introduced in more or less similar habitat in wild through conservation breeding programme for rapid multiplication in order to sustain a viable population in wild. It is important to conduct regular monitoring of population that would provide valuable up-to-date information, to help identify the critical population and sites for prioritized conservation actions and to support and guide the protection of the species. It is necessary to study the demographic parameters, population dynamics, requirement of space and forage for sustained reproduction and social structure and behaviour. Ecological information relevant to conservation such as several factors affecting the demographic structure *viz.* lack of connectivity for recolonization, poaching and incidental mortalities, increased probability of disease should be prioritise to broaden the existing knowledge base. There still remain many knowledge gaps in the systematic and genetic status of Eld's deer. For instance, the Eld's deer has a complex phylogeny; few studies (Zhang et al., 2008a; Zhang et al., 2008b) reported *R. e. hainanus* as a distinct fourth subspecies while the study of Balakrishnan et al. (2003) based on their data does not recognize this. Thus this indicates that the status of *hainanus* needs a formal study to examine its accurate taxonomic position and relationship among the subspecies of Eld's deer. In the future, more research is required to determine the genetic population structure, variable enough to detect differences between all the three subspecies of Eld's deer (an extensive study of microsatellite loci). An extensive study is required to assess the relatedness and kinships among both wild and captive population of Eld's deer to determine the genetic population structure of each population/sub population so that changes in genetic variability due to inbreeding depression and founder events in the populations could be identified and appropriate conservation measures are taken.

Acknowledgements: We are thankful to Mr. P.R. Sinha, Director and Dr. V.B. Mathur, Dean at the Wildlife Institute of India for providing logistic and technical support. This paper is a part of the research project "Conservation Ecology of Sangai and its wetland habitat" sponsored by the Wildlife Institute of India, Dehra Dun.

REFERENCES

Arlyne, J., Chanthavy, V. and McShea, W. (2003); The road to recovery: status of Eld's deer (*Cervus eldi siamensis*) in Lao PDR . Wildlife Conservation Society Lao PDR Program, Smithsonian Institution.

Avise, J.C. (1994); Molecular markers, natural history and evolution. Chapman and Hall, New York.

Balakrishnan, C.N., Monfort, S.L., Gaur, A., Singh, L. and Sorenson, M.D. (2003); Phylogeography and Conservation Genetics of Eld's deer (*Cervus eldii*). *Mol Ecol.,* 12:1-10.

Bhumpakphan, N., Sukmasuang, R. and Chaiyarat, R. (2004); Thailand: The crossroad where two Eld's deer subspecies existed. In: B. Pukazhenthi (ed.) Workshop on Eld's deer conservation and restoration. Khao Kheow Open Zoo Chonburi Thailand 10-14.

Blower, J. (1983); Species Conservation Priorities in Burma. In: Mittermeier, R.A. & Konstant, W.R. (eds), Species Conservation Priorities in the Tropical Forests of Southeast Occasional Papers of the IUCN Species Survival Commission, No. 1. UNEP, IUCN & WWF Asia 53-58.

Corbett, G.B. and Hill, J.E. (1992); The mammals of the Indomalay region: a systematic review. Natural History Museum Publications, Oxford University Press 488pp.

Comincini S., Sironi M., Bandi C., Giunta C., Rubini M. and Fontana F. (1996) RAPD analysis of systematic relationships among the Cervidae. *J Hered.,* 76:215-221.

Cook C.E., Wang Y. and Sensabaugh G. (1999); A mitochondrial control region and cytochrome b phylogeny of sika deer (*Cervus nippon*) and report of tandem repeats in the control region. *Mol Phylogenet and Evol.,* 12: 47-56.

Dang, N.X. and Nguyen, T. (undated); Status and conservation of Eld's deer (*Cervus eldii*) in Vietnam. Institute of Ecology and Biological Resources, Hanoi, Vietnam.

Decoux, J.P. (1993); Introduction Global Herdbook 1900-93 (ed. Decoux JP) Museum National d'Histoire Naturelle Paris 218pp.

Ellerman J.R. and Morrison-Scott T.C.S. (1951); Checklist of Palaearctic and Indian Mammals, 1758 to 1947. British Museum (Natural History) Trustees, London.

FAO (1982); Kyatthin Wildlife Sanctuary: report on a survey of the area and a preliminary census of the thamin. Nature Conservation and National Parks Project FO:BUR/80/006. Field Report 7/82. FAO, Rangoon.

Gee, E.P. (1960); Report on the status of the brow-antlered deer of Manipur (India): October-November 1959 and March 1960. *J Bomb Nat Hist Soc.,* 57(3):597–617.

Gee, E.P. (1961); The brow-antlered deer of Manipur. *Oryx* 6(2):103–115.

Gilbert, C., Ropiquet, A. and Hassanin, A. (2006); Mitochondrial and nuclear phylogenies of Cervidae (Mammalia, Ruminantia): Systematics, morphology, and biogeography. *Mol Phylogenet Evol.,* 40:101–117.

Ginsburg, L., Ingavat, R. and Sen, S. (1982); A Middle Pleistocene (Loagian) cave fauna in Northern Thailand. Comptes Rendus de l'Académie des Sciences, Paris 294: 295–297.

Groves, C. (2006); The genus *Cervus* in eastern Eurasia. *Eur J Wildlife Res*., 52:14-22.

Grubb, P. (2005); Artiodactyla. In: D.E. Wilson & D.M. Reeder (eds), Mammal Species of the World. A Taxonomic and Geographic Reference (3rd ed), Johns Hopkins University Press, Baltimore, USA 637-722.

Guha S. and Kashyap V.K. (2005); Development of novel heminested PCR assays based on mitochondrial 16s rRNA gene for identification of seven Pecora species. *BMC Genetics* 6:42.

Guha S., Goyal S.P. and Kashyap V.K. (2007); Molecular phylogeny of musk deer: a genomic view with mitochondrial 16S rRNA and cytochrome b gene. *Mol Phylogenet Evol.,* 42(3):585-597.

Hussain, S.A., Singsit, S., Ngailian, V., Angom, S. and Jhalai, K. (2006); The brow antlered deer of Manipur *Cervus eldii eldii*, McClelland 1842: A review of their status, ecology and conservation. *Indian Forester* 132(12):40-50.

Johnson, A., Vongkhamheng, C. and McShea, W., (2004); The road to recovery: status of Eld's deer (*Cervus eldii siamensis*) in Lao PDR. In: B. Pukazhenthi (ed.), Workshop on Eld's Deer Conservation and Restoration, pp.7-8. Khao Kheow Open Zoo, Chonburi, Thailand.

Khan, I., Prasad, N. and Mathur, P.K. (1992); Management of an endangered cervid: A case study of Manipur Brow-antlered deer (*Cervus eldii eldii).* Population and habitat viability assessment workshop briefing book for sangai volume II contributed articles and reports. Zoo Outreach Organization Coimbatore. India.

Kotmongkhon, S. (1997); Species diversity habitat and the status of wild mammals and birds of Yot Dom Wildlife Sanctuary. Wildlife Conservation Division, Royal Forest Department.

Koy, K., McShea, W.J., Leimgruber, P., Haack, B.N. and Aung, M. (2005); Percentage canopy cover using Landsat imagery to delineate habitat for Myanmar's endangered Eld's deer (*Cervus eldi*). *Anim Conserv.,* 8:289-296.

Lekagul, B. and McNeely, J.A. (1977); Mammals of Thailand. Kurushpa Ladprao Press, Bankok, Thailand.

Lekagul, B. and McNeely, J.A. (1988); Mammals of Thailand. 2nd ed. Sahakarn Bhaet, Bangkok, Thailand.

Linda, K.P. and Paul, M. (1995); Development in molecular genetic techniques in fisheries. Molecular Genetics in Fisheries. Edited by Gary R. Carvallo and Tony. In: J. Pitcher. Chapman and Hall, London.

Liu, Z.H. (1998); Cervus *eldii hainanus*. In: China Red Data Book of Endangered Animals (ed. Wang S) Science Press, Beijing, Hong Kong, New York 262–265pp.

Ludt C.J., Schroder W., Rottmann O. and Kuehn R. (2004); Mitochondrial DNA phylogeography of red deer (*Cervus elaphus*). *Mol Phylogenet and Evol*., 31:1064–1083.

Lydekker, R. and Dollman, J.G. (1985); The Game animals of Indian, Sub- continents. International books & periodicals supply service. New Delhi.

McClelland, J. (1941); The Calcutta Journal of Natural History. Vol II. International book distributers Dehra Dun India 415-417pp.

McClelland, J. (1942); The Calcutta Journal of Natural History. Vol III. International book distributers Dehra Dun India 401-409pp.

McShea, W.J., Leimgruber, P., Aung, M., Monfort, S.L. and Wemmer, C. (1999); Range collapse of a tropical cervid (*Cervus eldi*) and the extent of remaining habitat in Central Myanmar. *Anim Conserv.,* 2:173-183.

McShea, W.J., Aung, M., Poszig, D., Wemmer, C. and Monfort, S.L., (2001); Forage, habitat use, and sexual segregation by a tropical deer (*Cervus eldii thamin*) in a dipterocarp forest. *J Mammol.,* 82:848-857.

McShea, W. (2002); Laos Trip Report April 15-May 3. 2002, pp. 4. Smithsonian Institution.

McShea, W.J., Koy, K., Clements, T., Johnson, A., Vongkhamheng, C. and Aung, M. (2005); Finding a needle in the haystack: Regional analysis of suitable Eld's deer (*Cervus eldi*) forest in Southeast Asia. *Biol Conserv.,* 125:101-111.

Owen, M. (2009); Habitat suitability modelling for Eld's deer *Rucervus eldii siamensis* northwest Cambodia. A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science and the Diploma of Imperial College London.

Pang, J.F., Hoelzel, R., Song, Y.L., Zeng, Z.G. and Zhang, Y.P. (2003); Lack of mt DNA control region variation in Hainan Eld's deer: consequence of recent population bottleneck. *Conserv Genet.,* 4:109–112.

Pitra, C., Fickel, J., Meijaard, E. and Groves, C.P. (2004); Evolution and phylogeny of old world deer. *Mol Phylogenet Evol.,* 33:880–895.

Pocock, R.I. (1943); The larger deer of British India. Part II. *J Bomb Nat Hist Soc.,* 43:553–572.

Primack, B.R. (1993); Essentials of conservation biology. Sinnaur Associates, Inc. Sunderland, Massachusetts U.S.A. 564pp.

Polziehn R.O. and Strobeck C., (2002); A phylogenetic comparison of red deer and wapiti using mitochondrial DNA. *Mol Phylogenet Evol*., 22:342-356.

Randi, E., Mucci, N., Claro Hergueta, F., Bonnet, A. and Douzery, E.J.P. (2001); A mtDNA control region phylogeny of the Cervinae: speciation in *Cervus* and implications for conservation. *Anim. Conserv.,* 4:1-11.

RanjitSinh, M.K. (1975); Keibul Lamjao Sanctuary and the Brow-antlered deer -1972 with notes on a visit in 1975. *J Bomb Nat Hist Soc.,* 72(2):243-255.

Round, P.D. (1998); Wildlife, habitats, and priorities for Conservation in Dong Khanthung Proposed National Biodiversity Conservation Area, Champasak Province, Lao PDR. Pp. 198. CPAWM/WCS Cooperative Program, Vientiane, Lao PDR.

Salter, R.E. and Sayer, J.A. (1986); The brow-antlered deer in Burma: its distribution and status. *Oryx* 20: 241-245.

Shamungou, Kh. (1997); *Sangai*. 2nd Edn. Sangai Publishers, Nambol 118pp (in Manipuri).

Singh, T. (1992); Population and habitat viability: Assessment workshop. Briefing book of sangai, (Eds) Sally Walker, CBSG, India, Mysore Population dynamics of sangai.

Singsit, S. (2003); The Dancing deer of Manipur. Wildlife Institute of India. *Newsletter* 10(3): 5-7.

Singhasenee, A. (1996); La-ong, La-maung: One of the Thai National Reserved Species. Thai Zoological Park Organization. *Newsletter* 1(1):7-10.

Song, Y.L. and Li, S.Y., (1995); Estimating carrying capacity of Hainan National Nature Reserve for Eld's deer. *Acta Zool Sin.,* 41:275–281.

Song, Y.L. (1993); The causes for population size and distribution range changes of Hainan Eld's deer during forty years. In: Xia W.-P. & Zhang J. (eds), The Successional Changes of Mammals in China under the Influences of Human Activities. China Science and Technology Press, Beijing, China 102–107.

Song, Y.L. (1996); Population viability analysis for two isolated populations of Hainan Eld's Deer. *Conserv Biol.,* 10:1467–1472.

Song, Y.L., Li, S.Y. (1992); On population dynamics of Hainan Eld's deer (*Cervus eldi hainanus*) in Datian Nature Reserve, Hainan. *Acta Zool Sin.,* 38:165–171.

Soulé, M.E. (1980); Thresholds for survival: Maintaining fitness and evolutionary potential, in conservation biology: An evolutionary-ecological perspective. Soulé, M.E. and B.A. Wilcox (Eds). Sinauer, Massachusetts 151-170.

Tate, M.L., Anderson, R.M., Mc. Evan, K.M., Goosen, G.J. and Pearse, A.J. (1998); Genetic analysis of farmed deer hybrids. *Acta Vet. Hung.,* 46(3):329-340.

Tanomtong, A., Kongngarm, N., Supanuam, P. and Monthatong, M. (2008); Cytogenetic study on Thai brow-antlered deer, *Cervus eldi siamensis* and Thamin brow-antlered deer, *Cervus eldi thamin* (Artiodactyla, Cervidae) by conventional staining method. Songklanakarin; *Journal of Science and Technology* 30(2):171-177.

Thevenon, S., Claro, F., Bonnet, A. and Volobouev, V. (2000); Karyotype identity of two subspecies of Eld's deer [*Cervus eldi* (Cervinae, Artiodactyla)] and its consequences for conservation. *J Hered.,* 91:402-405.

Timmins, R.J. and Duckworth, J.W. (2008); *Rucervus eldii*. In: IUCN 2008. 2008 IUCN Red List of Threatened Species.

Thomas, O. (1918); The nomenclature and the geographical forms of the panolia deer (*Rucervus eldii*) and its relatives. *J Bomb Nat Hist Soc.,* 23: 363-367.

Tordoff, A.W., Timmins, R.J., Maxwell, A., Keavuth, H., Vuthy, L. and Hourt, K.E. (2005); Biological assessment of the Lower Mekong Dry Forests Ecoregion. pp. 192 WWF Greater Mekong Programme, Phnom Penh, Cambodia.

Tougard, C.Y., Chaimanee, V., Sutheethron, S. and Triamwichanon, Jaeger, J.J. (1996); Extension of the geographic distribution of the giant panda (Ailuropoda) and reasons for its progressive disappearance in Southeast Asia during the Latest Middle Pleistocene. C.R. Acad. Sci. Paris 973-979.

Vongkhamheng, C. and Phirasack, S. (2002); Eld's deer (*Cervus eldii siamensis*) surveys in Chonbuly district, Savannakhet province, Lao PDR. Pp. 38. Wildlife Conservation Society, Vientiane, Lao PD.

Wang, X., Manchard, N., Xicai, Y. and Claro, F. (2001); Biology and conservation of Eld's deer in China. In Global Herdbook of Elds Deer (eds Manchard N, Mauget C) 15-21. Museum National d'Histoire Nauturelle, Paris.

Wayne, R.K. (1991); Conservation genetics of the endangered Isle Royale gray wolf. *Conserv Biol.,* 5:41-51.

Wemmer, C. (1998); Deer status survey and Conservation Action Plan, p.107. IUCN /SSC Deer Specialist group Cambridge.

Wilson, D.E. and Reeder, D.A. (2005); Mammal Species of the World: A Taxonomic and Geographic Reference, 3rd edn. Johns Hopkins University Press, Baltimore.

Whitehead, K. (1993); The Whitehead encyclopaedia of deer. Shrewsbury: Swan- Hill press.

Xu, L.H. and Liu, Z.H. (1974); Investigation on Eld's deer in Hainan Island. *Chinese Journal of Zoology* 3:39–40.

Xu, L.H., Liu, Z.H., Liao, W.P., Lix, H., Yus, M., Qiuj, C., Zhou, Y.Y., Deng, J.X. and Guan, G.X. (1983); The Birds and Mammals of Hainan Island. Science Press, Beijing China 398–401.

Yu, S.M., Liu, Z.H. and Yuan, X.C. (1984); Resource, conservation and utilization of Hainan Eld's deer. *China Wildlife* 5(5):9–12.

Yuan, X., Lu, B., Chen, W., Liu, Z., Lu, C., Yun, D. and Chen, K. (1993); Population dynamics of Hainan Eld's deer in the State Datian Nature Reserve, Hainan Island. In: N. Ohtaishi and H. I. Sheng (eds), Deer of China: Biology and Management. Proceedings of the International Symposium on Deer of China 249-257. Elsevier, Oxford, UK.

Yuan, X.C., Xue, C., Yun, D.X., Wang, C.X. and Li, S.Y. (2001); Insite and offsite conservation of Hainan Eld's deer. *China Wildlife* 21:6–8.

Zeng, Y., Jiang, Z. and Li, C. (2007); Genetic variability in relocated Pére David's deer (*Elaphurus davidianus*) populations-Implications to reintroduction program. *Conserv Genet.,* 8:1051–1059.

Zeng, Z.G., Song, Y.L., Li, J.S., Ten, L.W., Zhang, Q. and Guo, F. (2005); Distribution, status and conservation of Hainan Eld's deer (*Cervus eldi hainanus*) in China. *Folia Zool.,* 54:249–257.

Zhang, Q., Zeng, Z.G., Ji, Y.J., Xing, D., Zhang, D.X and Song, Y.L. (2008a); Microsatellite variation in China's Hainan Eld's deer (Cervus eldi hainanus) and implications for their conservation. *Conserv Genet.,* 9(3):507-514.

Zhang, Q., Ji, Y.J., Zeng, Z.G., Song, Y.L. and Zhang, D.X. (2005); Polymorphic microsatellite DNA markers for the vulnerable Hainan Eld's deer (*Cervus eldi hainanus*) in China. *Acta Zool Sin.,* 51:530–534.

Zhang, Q., Zeng, Z.G. and Song, Y.L. (2008b); Isolation and characterization of eight microsatellite loci for the vulnerable Hainan Eld's deer (*Cervus eldii hainanus*) in China. *Conserv Genet.,* 9:965-967