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Biological Conservation 125 (2005) 101–111
BIOLOGICAL CONSERVATION
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Finding a needle in the haystack: Regional analysis of suitable Eld's deer (*Cervus eldi*) forest in Southeast Asia

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Received 16 September 2004
Available online 22 April 2005

Abstract

For species whose decline preceded the modern era and whose distribution is in the developing world, it is difficult to map suitable habitat across its former range. Eld's deer *(Cervus eldi*) is an endangered cervid whose range across Southeast Asia was reduced during the last century to disjoint populations in Myanmar and Cambodia. We used ecological data from the present populations to determine landscape and habitat parameters that would help us predict the occurrence of the species in forests not yet surveyed. The suitable-forest GIS model was created using four readily available datasets for elevation, forest type, canopy closure, and human density. Comparison of the GIS model with 24 verified sightings of Eld's deer during recent large mammal surveys in Cambodia, found 22 sightings (92%) within predicted suitable forest. Use the suitable-forest GIS model to survey a province in southern Lao People's Democratic Republic, located a single, previously unreported population from 9 patches surveyed. In a separate analysis, a logistic regression model to predict Eld's deer habitat in Northern Cambodia found percent tree cover, presence of wetlands, and distance to villages as the best predictors of deer, similar to variables used in the GIS model, with the exception of the importance of wetlands. Using mean annual rainfall to rank suitable-forest patches identified in the GIS model indicated dry dipterocarp forests in Northeastern Cambodia and Northern Myanmar have the highest potential to conserve eld's deer. Examination of the suitable-forest GIS map and current protected areas indicated only Cambodia, with 11% suitable forest protected, has placed sufficient dry dipterocarp forest under protected status. Other Southeast Asia countries have not recognized dry dipterocarp forest as a significant ecotype worthy of conservation status.

Keywords: Cervids; Dry dipterocarp forest; Landscape ecology; Protected areas; Suitable forest; Northern plains of Cambodia; Reintroduction

1. Introduction

Habitat loss is a critical threat to most endangered species (Diamond, 1984; Lu et al., 2000; Orians and Soulè, 2001) and delineation of available habitat (McShea et al., 1999; Leimgruber et al., 2003) or potential of sites to host translocated populations (Wolf et al., 1996; Boyce and Waller, 2003) is a major focus of conservation efforts (Orians and Soulè, 2001). For species that are presently contracting their range, such as migratory birds in North America, it is possible to map distributions and test hypotheses on the pattern of species loss (Rodriguez, 2002). For many endangered species,

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doi:10.1016/j.biocon.2005.03.013

however, range reduction preceded the advent of concerted conservation efforts. Generalized descriptions of habitat and location from historical records are often difficult to convert to modern metrics and, once located, a habitat's current condition rarely matches its historic condition. For example, the success of black-footed ferret (*Mustela nigripes*) reintroductions depends on the viability and distribution of prairie dog (*Cynomys* sp.) colonies, whose current extent is 98% below historic levels and whose persistence depends on both disease dynamics and government control programs (Miller et al., 1996). Historic locations of black-footed ferrets would not facilitate decisions on where present reintroduction efforts should focus.

An alternative approach is to use modern distributions as a predictor of suitable habitat across the former range (Corsi et al., 2000). This inductive approach might allow for testing predictive models using some subset of the current populations. However, the tendency for species to persist along the periphery, and not the center, of its former range (Lomolino and Channell, 1998; Channel and Lomolino, 2000a,b; Laliberte and Ripple, 2004) makes this approach problematic. In addition, whereas, current relict populations may occupy a single habitat type (e.g. giant pandas *Ailuoropoda melanoleuca* are confined to high elevation bamboo forests), the historic range may be composed of multiple habitats that are no longer available for selection by current populations, yet remain viable for a species' persistence (Lu et al., 2000). This problem would tend to underestimate the amount of available habitat, particularly outside the present range of the species.

Among mammals, the ungulate family is particularly sensitive to decline (Mace and Balmford, 2000; Laliberte and Ripple, 2004) and is responsive to protection within a reserve system (Caro et al., 2000). Of the 10 ungulate species in North America, 7 have contracted their range over 20% in the last century (Laliberte and Ripple, 2004). Caro et al. (2000) found 10 ungulate species at higher densities inside protected areas in Tanzania, when compared to outside the park boundaries. Due to their size and relatively broad diet, large herbivores are excellent candidates for translocation, if suitable habitat can be identified (Wolf et al., 1996).

Eld's deer (*Cervus eldi*) is an ungulate species whose only known populations are along the fringes of its original range throughout the dry forests of Southeast Asia (Wemmer, 1998). The Southeast Asian region had the highest vulnerability to extinctions among continental regions (Mace and Balmford, 2000) and the largest gaps in protection (MacKinnon, 2000). Eld's deer are usually considered to include three subspecies; *C. eldi siamensis*, *C. eldi eldi*, and *C. eldi thamin* (Pocock, 1942; Whitehead, 1993; Balakrishnan et al., 2003). Only the last subspecies has been well studied in natural populations in central Myanmar (Aung et al., 2001; McShea et al., 2001). The entire species is listed on CITES Appendix 1 and vulnerable in the IUCN Red List, with subspecies listed as critical (*C. eldi eldi*) to data deficient (*C. eldi siamensis*) (IUCN, 1997; Wemmer, 1998).

The three subspecies of Eld's deer all occupy open forests, but occur across a wide range of moisture regimes. The last remaining population of *C. e. eldi* inhabits floating mats of dense vegetation within a small (<15 km^2) region in Manipur, India (Geist, 1998). In contrast, *C. e. thamin* are most often found in dry, deciduous dipterocarp forests with an open understory in central Myanmar (Wemmer, 1998; McShea et al., 1999). In this region the southwest monsoon results in heavy rainfall (up to 5000 mm) on the fringes of Eld's deer habitat (i.e. the hilly borders of the Irrawaddy plain) to 750 mm in the Eld's deer primary habitats (Davis, 1960; Salter and Sayer, 1986). Pristine habitat is non-existent for *thamin*, and they now inhabit areas that range from dry scrub and thorn forest to open deciduous forest in various stages of secondary succession (Aung, 1994; McShea et al., 1999).

C. eldi. siamensis was considered extinct in the wild until recently, but historically was found in habitats similar to *thamin* (Salter and Sayer, 1986; Duckworth et al., 1999). In 1998 a single population of *siamensis* was reported for southern Lao, near the tri-border region with Cambodia and Thailand (Round, 1998). The recent increased survey activity in Cambodia has resulted in multiple photographs of Eld's deer, primarily along the country's northern border with Thailand and northeastern provinces. The rediscovery of this sub-species has reconfirmed the notion that suitable forest still exists for this species in Southeast Asia and now is the time to create plans for conserving appropriate forest patches.

There has been a steady decline in the *thamin* populations in Myanmar since the 1940s (Yin, 1967; Salter and Sayer, 1986; McShea et al., 1999). A country-wide survey conducted in 1992 estimated that 2200 individuals remained (Aung, 1994), while a 1997 survey estimated 1750 animals (McShea et al., 1999). The largest population remains in Chatthin Wildlife Sanctuary, but this population declined 40% between 1983 and 1995. Protected areas in Myanmar are under severe stress, due to internal and external economic factors (Brunner et al., 1998; Rao et al., 2002). If forests within the previous range are still suitable for the species, they might serve as translocation sites, if conditions in Myanmar deteriorate. There is also an effort by the zoological community in Thailand to reintroduce both *siamensis* and *thamin* from captive stocks presently held in the country's zoos (Pukazhenthi, 2004).

The objective of this research was to create a suitable-forest GIS model for Eld's deer using existing field data from Myanmar, and readily available GIS data layers, that will serve to guide conservation decisions; to test this model with newly discovered populations of the deer in Southeast Asia; and, if the model proves viable, to examine the potential of the present reserve system in Southeast Asia to support either translocated or reintroduced Eld's deer populations.

2. Methods

2.1. Study area and data

The study area included the Southeast Asian countries of Cambodia, Myanmar, Lao, Thailand and Vietnam (Fig. 1). These countries comprise the majority of the deer's historic range and contained the only known naturally occurring Eld's deer at the start of this research (McShea et al., 1999). There is a population of *C. eldi siamensis* in Hainan, China (Song, 1996), and a population of *C. eldi eldi* in Northern India (Prescott, 1987), however both these populations are disjoint from the historic range and are in heavily modified habitats.

2.2. GIS data layers and model creation

This regional analysis was conducted using global coverage data layers that are readily available and Eld's deer survey and habitat selection data obtained through prior research in Myanmar (McShea et al., 1999; McShea et al., 2001). Five global data sets were used: The United States Geological Survey Global Land Cover Characterization Data (http://edcdaac.usgs.gov/glcc/glcc.html) for land cover classification (Loveland et al., 2000); United States Geological Survey Global 30 Arc-Second Elevation Data Set (http://edcwww.cr.usgs.gov/products/elevation/gtopo30.html) for elevation; University of Maryland's Continuous Fields Tree Cover Project (http://glcf.umiacs.umd.edu/treecover/index.html) to delineate percent canopy cove (Defries et al., 2000); and the Oak Ridge National Laboratory's landScan data (http://www.ornl.gov/gist/landscan/index.html) as a measure of ambient population (Bhaduri et al., 2002; Dobson et al., 2000). For moisture, we used the annual rainfall layer from Worldclim. (http://biogeo.berkeley.edu/worldclim/), which is defined by the website as the sum of all the monthly precipitation estimates. These data sources are coarse (1 km^2) resolution raster data appropriate for approximations over a large study area.

Expert knowledge was used to determine which parameters were important within each dataset. Repeated studies of *C. eldi thamin* in Myanmar have found lowland dry dipterocarp forest as preferred habitat for this species (Yin, 1967; Aung, 1994; Salter and Sayer, 1986; McShea et al., 1999, 2001). However, there is no single identifier for this forest type across the broad scale of Southeast Asia, so we combined criteria from multiple global data. We identified broadleaf deciduous forest within the United States Geological Survey Global Land Cover Characterization data to exclude areas with evergreen forest and non-forest landcover. Although dry dipterocarp forest can be found up to 1000 m elevation (Stamp, 1925; Davis, 1960), no Eld's deer populations have been located >400 m elevation (McShea et al., 2001), so the United States Geological Survey elevation data set was used to exclude forests above 400 m. All canopy cover measures taken within forests containing current Eld's deer populations in Myanmar fell between 15–45% (Koy et al., 2005). We used University of Maryland's Continuous Fields Percent Tree Cover Map to exclude all forests that fell outside these measurements. The landScan data was used to exclude all areas that had a value of more than 10 people per pixel. This cutoff was determined by the approximate value seen around known Eld's deer locations. These raster data sets were intersected using the map calculator function in the Earth Science Research Institute's (ESRI) Arcview 3.3.

The created raster layer was smoothed using a 5 × 5 neighborhood function in ERDAS 8.5. The remaining raster data was then converted to vector polygons for analysis. All patches outside of the five-country study area and all patches smaller than 25 km^2 were eliminated. This area was determined to be the minimal forest size for present populations in Myanmar (McShea et al., 1999).

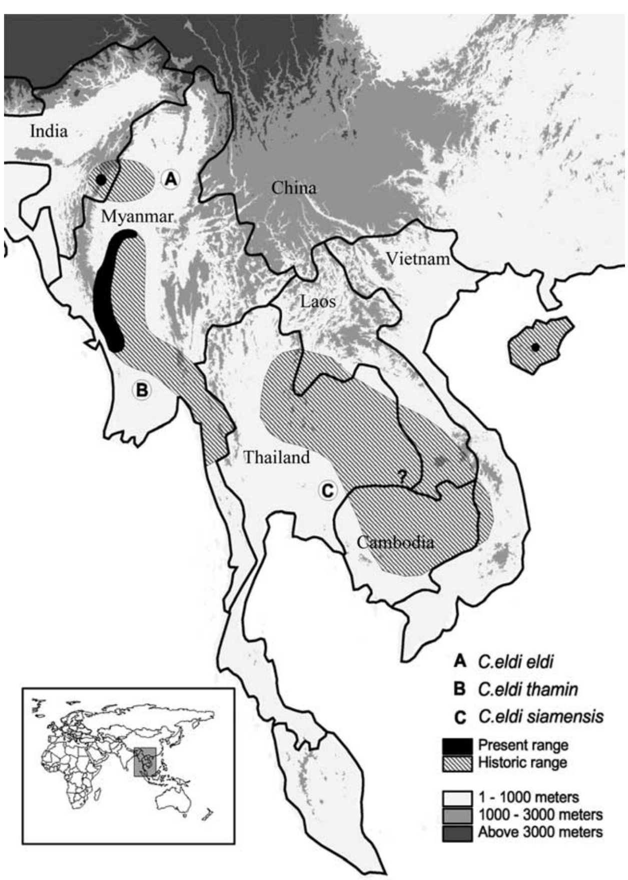

Fig. 1. The assumed historical and current distribution of Eld's deer in 2000 (modified from McShea et al., 1999).

2.3. Logistic model

We used ground surveys in Cambodia as an independent validation of landscape and forest cover variables to estimate suitable forest for *C. eldi siamensis*. Between 2001 and 2003 Wildlife Conservation Society conducted systematic surveys across the Northern Plains of Cambodia (17,000 km^2), primarily focused on two landscapes: Chhep (4880 km^2) and the Kulen Promtep Wildlife Sanctuary (6448 km^2) (Clements, 2004). Most surveys involved walking through areas that interviews indicated contained key species, although 93 five-km transects were also completed and cameras with an infra-red trigger (e.g. Karanth, 1994) were placed for a total of 4024 trap-nights. Surveys were conducted systematically, so that all available habitats were sampled by each methodology. A 1-km^2 grid was placed across a map of the two survey landscapes and 5292 km^2 (47%) were surveyed by one or more methodologies. Eld's deer presence within a block was considered a sighting, camera picture, or observing tracks of the animal.

The habitat was classified using the Japan International Cooperation Agency Landuse Dataset for Cambodia (2003), giving the number of hectares of deciduous and mixed deciduous forest, evergreen and riparian forest, and grasslands within each block. The University of Maryland's Continuous Fields Tree Cover Project was used to delineate percentage canopy cover (Defries et al., 2000). The area of wetlands within each square was based upon the 1970 topographic map for Cambodia, which was interpolated from aerial photography.

Human presence was determined by measuring the distance from the center of the block to the nearest major roads and settlements. Village locations were available from the 2001 national survey, updated by field survey teams in 2003. Since available road datasets are unreliable across the study area, field survey teams also mapped major roads.

Logistic regression (Hosmer and Lemeshow, 1989) was used to identify environmental variables that were significant predictors of deer presence or absence. Akaike's Information Criteria (AIC, Akaike, 1974) was used to help identify the most parsimonious model:

$$\mathrm{AIC} = [-2\ln(L) + 2P]/N,$$

where L is the value of the likelihood function, P is the number of parameters estimated (including the intercept) and N is the number of observations. Each possible combination of the models was analyzed, the best model being the one with the minimum criterion value. Competing models were those with criterion values $\leqslant \text{criterion}_{\min} + 4$. For the logistic regression, "presence" 1-km^2 blocks were compared to "absence" 1-km^2 blocks, where no evidence of Eld's deer were detected. Stratification was based on habitat type to insure 1-km^2 blocks were selected in proportion to the abundance of the habitat.

2.4. Field validation of GIS model

Cambodia: The ability of the GIS model to determine suitable forest in Southeast Asia was validated in Cambodia, where recent surveys to detect large mammals have resulted in several detections of Eld's deer. In addition to the surveys in the Northern Plains (Clements, 2004), vast areas in the country have been surveyed for large mammals (Olivier and Woodford, 1994; Desai and Vuthy, 1996). These surveys differed in their techniques but included aerial surveys (Olivier and Woodford, 1994), ground transects (Desai and Vuthy, 1996), and camera trapping (Clements, 2004). The surveys were compiled for a 2003 workshop on Eld's deer conservation (Weiler, 2004), inspected by one author for veracity (TC), and reduced to verified, georeferenced sightings or photographs. The country was divided into 410 20×20 km blocks and each block was identified as containing suitable forest according to our model and as containing detections of Eld's deer during the aforementioned surveys. The number of blocks correctly predicted to contain deer was compared to a random selection of the same number of blocks and the process was repeated 1000 times using a macro in Excel.

Lao People's Democratic Republic: Maps based on the model were used during 2 field trips to Lao People's Democratic Republic during 2002. All suitable forest patches identified in Savannakhet Province were inspected by automobile and on foot. At least one village in each patch was visited and we interviewed local officials and villagers about Eld's deer sightings. Interviews included photographs of Eld's deer to assist with identification. Reports of past presence of Eld's deer were confirmed with skulls and antlers. Reports of current populations were verified with ground transects for sightings and tracks.

2.5. Use of GIS model

Following validation of the GIS model with the Cambodia and Laos survey data; we used the logistic model results from Cambodia to modify the GIS model to incorporate moisture as a ranking variable. Area statistics were then analyzed for each country using the final Eld's deer suitable-forest layer. Protected areas coverage was obtained from the United Nations Environmental Program, World Conservation Monitoring Centre. We compared range countries with respect to the amount of suitable forest and its protection status. The steps of data acquisition and use are outlined in Fig. 2.

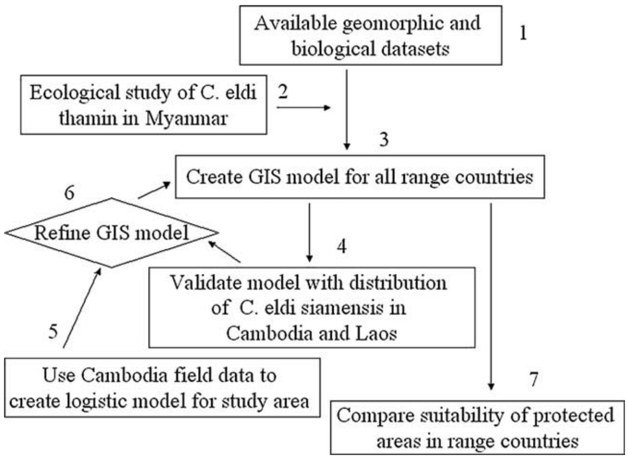

Fig. 2. Flow diagram of procedure to create, validate, and use a suitable-forest GIS model. Variables from existing databases (1) were selected and limits set based on habitat selection data obtained from fieldwork in Myanmar (2). The GIS model for Southeast Asia (3) was validated using survey data from Cambodia and Laos (4). A logistic regression model of the Cambodia field data (5) refined the GIS model (6) and the revised GIS model was used to examine present protected areas and forest cover in range countries (7).

3. Results

3.1. Logistic model variables in Cambodia

Of 5292 1-km^2 blocks surveyed for Eld's deer in the Northern Plains of Cambodia, 137 had evidence of deer. "Absence" 1-km^2 blocks were selected by a stratified random procedure, except that no block adjacent to "presence" block was considered due to possible errors in georeferencing and short-term movements of deer. A comparison of those "presence" blocks to 257 "absence" blocks shows the distribution of Eld's Deer in relation to habitat, human settlements and roads (Figs. 3 and 4). The graphs indicate that the deer are more likely to be found in deciduous forest areas, and wetlands, and avoid areas with high cover of evergreen forest. Deer presence also increased away from human settlements.

Logistic regression models were constructed using 122 presence and 184 absence blocks. The remaining 15 presence and 73 absence blocks were used to validate model predictions. Seven models were produced that predicted Eld's deer presence (Table 1). Model 1 has the lowest AIC value, although Model 2 could also be selected, as its AIC values are within 4 units. Both models correctly classified over 60% of presence and 80% of absence blocks, for data entered, and over 65% of presence and 80% of absence validation blocks. The best predictors of Eld's deer (*C. eldi siamensis*) in Cambodia are % tree cover, the presence of wetlands, lack of evergreen forest, and distance to villages. These variables are very similar to those used in our GIS model, except for the importance of wetlands. We would consider Model 1 as the 'best' model because it used the University of Maryland's Continuous Fields Tree Cover Project

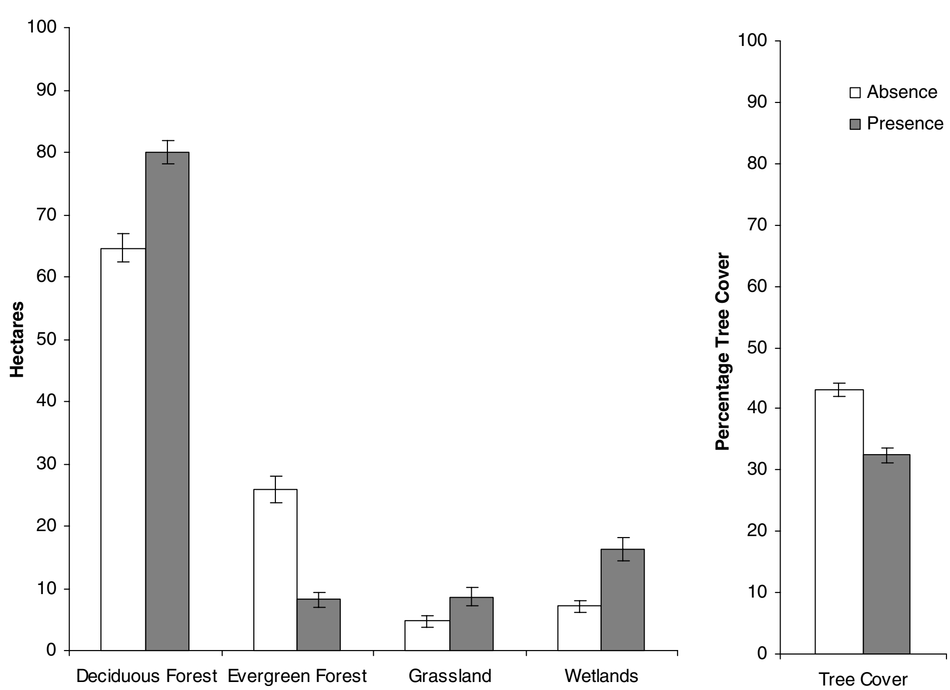

Fig. 3. The mean (±standard error) values for habitat variables measured within 1 km^2 blocks in Northern Plains of Cambodia. Deer were detected in 137 1-km^2 blocks and were compared to 257 1-km^2 where deer were not detected. Habitat was measured as the number of hectares of each type within the 1-km^2 block based on classification of 2003 Japan International Cooperation Agency Landsat image. Percent tree cover was estimated using the Marlyand's Continuous Fields Tree Cover Project.

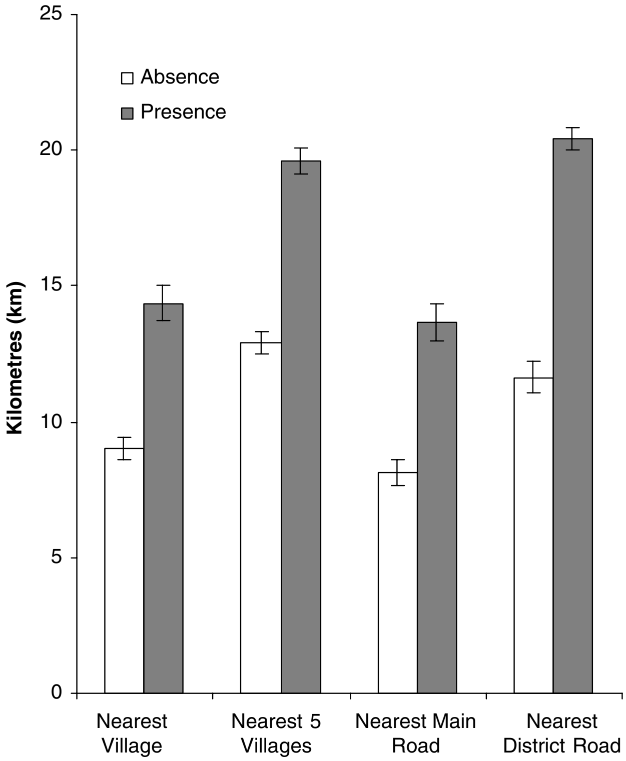

Fig. 4. The mean (± standard error) values for landscape variables measured within 1 km^2 blocks in Northern Plains of Cambodia. Deer were detected in 137 1-km^2 blocks and were compared to 257 1-km^2 where deer were not detected.

global dataset to measure habitat rather than a restricted GIS layer for only Cambodia.

3.2. Validation a suitable-forest GIS model in Cambodia and Laos

With Cambodia divided into 410 blocks (20 × 20 km), suitable blocks ($n = 143$) were located throughout the country, but concentrated in the northern and eastern forests (Fig. 5). Blocks with reports of Eld's deer ($n = 24$) overlapped with the suitable blocks on 92% of the occurrences. A Monte Carlo simulation of this result indicated a low probability of this degree of overlap being random ($P < 0.001$; 1000 simulations).

In April and December 2002, the suitable-forest GIS map was used to examine potential Eld's deer habitat in Savannakhet Province, in southern Laos. Nine potential habitat patches were inspected and villagers interviewed. Villagers reported 3 patches had contained Eld's deer at the onset of the regional conflict in the 1970s and one patch still contained a small population of Eld's deer (estimated <30 individuals; Vongkhamheng and Phirasack, 2002).

3.3. Protected suitable forest

Our suitable-forest GIS model for Southeast Asia was based on percent tree cover, elevation, human density, and deciduous forest (Fig. 6). The GIS model indicated that suitable forest remains in each of the former range countries. Myanmar contains the most suitable forest for Eld's deer according to our model, with Cambodia, Thailand, Lao, and Vietnam in descending order (Table 2). Cambodia and Myanmar also contained the large fragments (>1000 km^2) of suitable forest. Lao People's Democratic Republic, Thailand, and Vietnam contain neither an abundant amount of suitable forest, nor large patches of suitable forest.

Each country in the region has protected over 20,000 km^2 of forest (Table 3). With regards to Eld's deer, however, the amount of suitable forest protected never totals >650 km^2, except for Cambodia. Cambodia has protected 11.5% of its suitable forest, which is the best protection status in the region (Table 3). No other country in the region has protected more than 1% of its suitable forest.

The logistic model used to refine the GIS model indicated distance to water was a significant determinant of deer presence in Cambodia. The majority of these water bodies are seasonally inundated ponds that are produced during the monsoon rains and decrease in extent during the dry season. There are no regional datasets that track the distribution of these ephemeral water sources. We used a global dataset from Worldclim

Table 1
Logistic regression models that predicted Eld's deer presence within Northern Plains of Cambodia

Model	Variables in the Model	Parameters	AIC
1	Tree cover (%, −0.036), Wetlands (ha, 0.028), Nearest 5 villages (average distance in km, 0.148)	4	319.32
2	Evergreen forest (ha, −0.021), Wetlands (0.025), Nearest 5 villages (0.150)	4	322.25
3	Tree cover, Nearest 5 villages	3	332.26
4	Wetlands, Nearest 5 villages	3	333.78
5	Nearest 5 villages	2	349.33
6	Evergreen forest	2	384.54
7	Tree cover	2	381.57

The units used for each variable is given in parentheses when first encountered. The model with lowest AIC value (Model 1) is usually preferred and coefficients for variables used for that model and the closest model are given in parentheses.

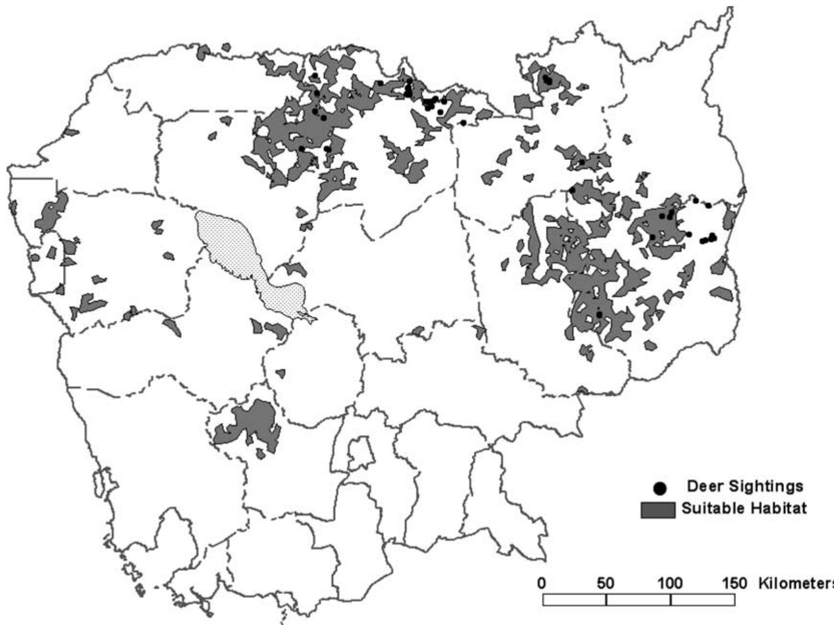

Fig. 5. Suitable-forest GIS model for Cambodia, with verified sightings of Eld's deer during recent large mammal surveys.

(http://biogeo.berkeley.edu/worldclim/) for mean annual rainfall amounts to indicate forests that might possess more of these pools. The forest patches identified in the suitable-forest GIS model were ranked according to mean annual rainfall recorded in the area (Fig. 7). Suitable-forest patches in Northeastern Cambodia and Northern Myanmar appear to possess the highest potential for containing surface water throughout the year.

4. Discussion

In a meta-analysis of translocation programs (Wolf et al., 1996), the amount of suitable habitat available was an important factor determining success. For countries such as Thailand, where Eld's deer have been extirpated for 35 years and are being considered for reintroduction (Pukazhenthi, 2004), determining the extent of suitable forest is not an easy task. Our suitable-forest GIS model, based on our knowledge of current *thamin* populations in Myanmar, did predict the occurrence of populations in Cambodia and Lao. The variables used closely matched those identified from a logistic model based on ground surveys of *siamensis* in Cambodia. This success indicates the GIS model can be used to identify sites to reintroduction of either *thamin* or *siamensis* into Thailand. It is not encouraging that the GIS model indicates only small patches of suitable forest remain in Thailand.

The inductive modeling of known populations of rare species to help locate "lost" populations has been successful in plant species (Boetsch et al., 2003; Bourg, 2005). It is less common to use this procedure with mammals, in part because mammal species are usually not as cryptic as many plants. In developing countries that are primarily forested, however, the logistics of covering large areas on the ground makes even large mammals cryptic. Inductive modeling, such as our suitable-forest model, offers an efficient means to reduce search areas and conserve conservation resources.

The reliance of these deer on dry deciduous dipterocarp forest (McShea et al., 1999, 2001) makes the delineation of suitable forest relatively easy, but the potential for conservation relatively difficult. Dry dipterocarp forest was historically distributed across the central plain of Southeast Asia (i.e. in Thailand, Cambodia, and Lao) and along the perimeter of the dry plains of Myanmar (Wikramanayake et al., 2002). The distinctiveness of the regions is due to animal species, such as *Myotis altarium* and hooded treepies (*Crypsirina cucullata*), which are endemic to fire-dependent tropical communities. These ecoregions have lost most of their large mammal contingent, such as tigers (*Panthera tigris*), leopards (*Panthera pardus*), dholes (*Cuon alpinus*), Schomburgk's deer (*C. schomburgki*), and kouprey (*Bos saulveli*). The conservation status of the 2 ecoregions is considered vulnerable and critical, respectively, due to forest conversion to agriculture (Wikramanayake et al., 2002). This loss of dry forest is not confined to Southeast Asia, with severe losses also noted in the neotropics (Bullock et al., 1995; Trejo and Dirzo, 2000).

In Asia, dry dipterocarp forests at low elevations and within monsoon climates are excellent candidates for conversion to rice production (Murphey and Lugo, 1986; Rundel and Boonpragob, 1995) and not for inclusion in protected areas. With the possible exception of Cambodia, the present protected area system does not adequately protect Eld's deer habitat. Beyond the 11%

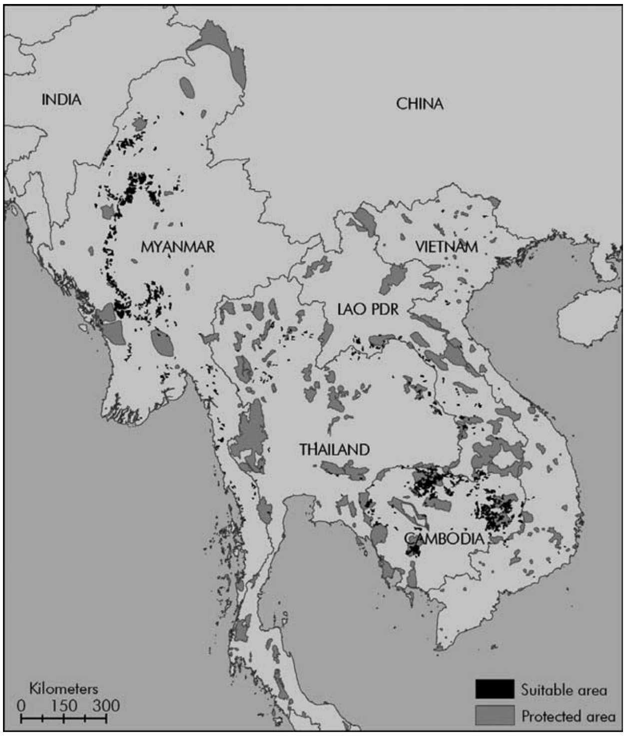

Fig. 6. Final suitable-forest GIS model for range countries with overlay of current protected areas.

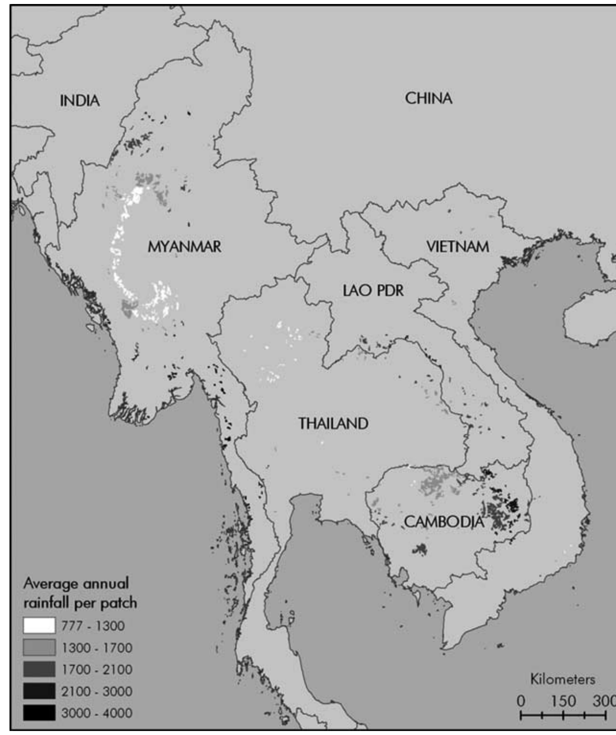

Fig. 7. Final suitable forest GIS model with forest patches ranked based on the amount of annual rainfall received in the area.

Table 2
Results of model used to identify suitable forest cover for *Cervus eldi* within each country and across the region

Country	Total forest (km^2)	Suitable forest (km^2) (%)	Country's contribution to total (%)	Number of suitable patches	Maximum patch size (km^2)	Mean patch size (km^2)
Myanmar	644,813	20,678 (0.32)	46.4	140	1709	147
Thailand	277,443	3176 (1.1)	7.1	58	214	54
Laos	261,023	2264 (0.82)	5.1	34	220	25
Vietnam	206,313	738 (0.32)	1.7	17	95	43
Cambodia	134,923	17,673 (13.1)	39.7	67	4618	263
Region	1,524,515	44,529 (2.92)	100	316	–	130.0

Table 3
The total and relative amount of suitable forest within protected areas for each country and for the region

Country	Total protected forest (km^2)	Protected forest suitable for deer (km^2) (%)	Number of suitable protected patches	Estimated deer numbers
Myanmar	33,129	172 (0.5)	11	1800
Thailand	64,504	620 (1.0)	20	0
Laos	40,367	404 (1.0)	11	<50
Vietnam	21,303	12 (0.0)	3	0
Cambodia	34,139	3822 (11.2)	37	<150
Region	193,442	5030 (2.6)	82	2000

Estimates of deer numbers are based on expert opinions, except for actual census data in Myanmar (McShea et al., 1999). Patches were considered protected if any portion of the patch fell within a protected area.

of suitable forest protected in Cambodia, suitable forest never exceeded 1% of the protected forests in the other Southeast Asian countries. This is the unintended consequence of protecting mountain habitat or moist tropical rainforest, when designing country-wide conservation plans.

The planned restoration efforts for Eld's deer in Thailand (Pukazhenthi, 2004) would need to produce detailed maps at the province or district level and there are two modifications that would improve our GIS model's ability to produce accurate maps. First, this analysis was conducted with course-resolution datasets that are readily available and low cost. A previous study of remote identification of dry dipterocarp forest showed that most misclassifications are between agriculture and forest, as dry dipterocarp forest type has <20% canopy closure (Koy et al., 2005). We would recommend use of a higher spatial resolution satellite image data such as Landsat Thematic Mapper, in order to reduce misclassifications. Second, although both *thamin* and *siamensis* subspecies need to be reintroduced within the historical range, *siamensis* is the more critical (Pukazhenthi, 2004). This model was produced using *thamin* population data and could be recalibrated using the recently discovered *siamensis* populations in Cambodia and Lao.

This recalibration might be important because it not obvious that the present range of habitats for *thamin* reflect the species' original niche breadth. There is good evidence that the present habitat distribution of the Eld's deer, particularly *thamin*, is one branch of its phylogenetic history. Although *thamin*, and the recently located *siamensis* populations, were found in dry dipterocarp forests with monsoon rains, cervids of close lineage are all adapted for moister forests. The Eld's deer belongs to the subgenus *Rucervus* that consists of two species that inhabit fresh-water marshes, the barasingha (*C. duvauceli*), and the extinct Schomburgk's deer (Geist, 1998). Although the relationships within this group have not been assessed using molecular data, a recent phylogenetic study placed the Eld's deer within a *Cervus* clade that contained the above-mentioned species and the marsh-adapted Pere David's deer (*Elaphurus davidianus*) (Randi et al., 2000). Lekagul and McNeely (1977) proposed that the lineage inhabited swampy areas and Eld's deer were more recently driven into the drier habitats due to the pressures imposed by hunting and the expansion of agricultural areas. The subspecies *eldi* evidently has continued a mesic habitat association and is confined to a single marsh in India (Ranjitsinh, 1978). The single population of Eld's deer in Champasak Province, Lao, inhabits a marshy area similar to the conditions described by Lekagul and McNeely (1977). The logistic regression models presented in this paper for deer sighted in the Northern Plains of Cambodia indicate wetlands are important and there are also reports of Eld's deer at Ang Trapeang Thmor Reserve, a marsh lake in northwestern Cambodia (Clements, personal communication). This evidence indicates moister dipterocarp forests or grasslands have the potential for productive deer habitat that is not realized in the present distribution. We used a course measure of moisture within these forests by ranking the suitable-forest patches using a dataset for mean annual rainfall (Fig. 7). This ranking also pointed to the importance of dry dipterocarp forest in Northeastern Cambodia and Northern Myanmar. The mapping process could be improved through production of a regional dataset that accurately reflects surface water and soil moisture.

It is hopeful that Cambodia has large reserves along its northern border that are appropriate for the deer and contain several of the recent "found" populations. For the parks and reserves used in the analysis, we have made the supposition that the host countries are equal in their ability to protect species residing within their boundaries. This project identified potential habitat, but we have no ability to detect the amount of protection deer would receive within these forest patches. The marked economic inequalities between nations within Southeast Asia (Balmford and Long, 1995), however, do not support the supposition that all forests are equal. Whereas, Thailand might be in the best economic and bureaucratic position to protect Eld's deer, they have no resident populations. Most deer reside within Cambodia and Myanmar, which are on the opposite end of the economic spectrum from Thailand, with regards to infrastructure and monetary support of conservation (Balmford and Long, 1995). Protected areas within Myanmar, which have the largest populations of *thamin*, are in critical condition due to lack of funds and political will (Rao et al., 2002). There is a need to develop a mechanism where these less-developed countries are supported in their conservation efforts by other range countries or international organizations. A recent workshop in Thailand was a first step toward a cooperative effort involving all range countries (Pukazhenthi, 2004).

Acknowledgments

We thank field teams that completed surveys in Myanmar, Cambodia, and Lao. Hunter Weiler alerted us to the data available in Cambodia. The work was funded by internal funds from the Smithsonian Institution's National Zoological Park and the Wildlife Conservation Society. We thank two anonymous reviewers, whose comments greatly improved the manuscript.

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