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Range collapse of a tropical cervid (*Cervus eldi*) and the extent of remaining habitat in central Myanmar

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Abstract

The thamin (*Cervus eldi*) is an endangered species of deer whose present range is greatly reduced from its original distribution covering the deciduous forests throughout south-east Asia. We mapped the present distribution of thamin using ground surveys and tied this information to habitat types derived from satellite images in order to detect patterns that might indicate the landscape features which precipitated the decline. We conducted a survey of 24 out of 28 Myanmar townships that were reported to contain thamin in 1992, and evidence of thamin were found in 23 of these townships, predominately in mixed deciduous forests where dipterocarp trees were present. There was no significant correlation between the number of thamin detected and forest remaining in the township, or the size of the human or livestock population. A landcover classification of Landsat Thematic Mapper images indicated 58% of the study area contained deciduous forest, of which 12% was dipterocarp forest. Forest tracts containing thamin were digitized and landscape analyses were conducted on a resampled habitat map that emphasized dry and dipterocarp deciduous forest. Of six landscape variables measured only core area size was a significant predictor for the presence of thamin. None of the unsurveyed indaing forest tracts possessed a core area large enough to support thamin. The pattern of thamin decline matches predictions that peripheral, rather than central, populations are more likely to persist in declining species.

INTRODUCTION

The conservation of large mammals in tropical ecosystems is a difficult task, due to many factors, including fragmentation of remaining refuges (Laurence, 1991; Newmark, 1996), and poaching for food (Alvard *et al*., 1997; Bodmer, Eisenberg & Redford, 1997), trophies, or medicinal products (Geist, 1994; Heinen & Srikosamatara, 1996). Consensus on protecting large mammals is complicated by conflicts between animals and agriculture (Fox, Yonzon & Podger, 1996; but see Saberwal, 1996), their distribution across political and legal boundaries (Keiter & Locke, 1996), and by competition between conservation organizations (Rabinowitz, 1995). Increasing human populations threaten tropical forest ecosystems and all large mammals associated with these systems. This problem is compounded by the relative lack of protection and funding for many tropical countries (Balmford & Long, 1995). We report on our effort to assess the remaining range and available habitat for a rapidly disappearing cervid, the thamin or Eld's deer (*Cervus eldi thamin*), now restricted to Myanmar, a tropical country experiencing many of the problems that impede conservation efforts for large mammals. Our purpose is to use the decline of thamin as a case study of which landscape and habitat features are tied to the decline of a large mammal species in tropical forests.

The Eld's deer (*C. eldi eldi*) was first discovered in the Manipur Valley of India in 1838 by a British army officer, Lieutenant Percy Eld. Three subspecies are recognized as occurring in India, Myanmar and Indo–China (Whitehead, 1972). During this century, the once widespread species has disappeared throughout most of its range (Fig. 1). By 1945 it was described as rare or endangered throughout the southern portions of its range (Harper, 1945), and the western subspecies in Manipur (*C. eldi eldi*) was considered extinct until a small population was located in the 1950s (Ranjitsinh, 1978). In 1986, *C. eldi eldi* was restricted to 100 individuals in Indian zoos and 50 individuals in Keibul Lamjao National Park, Manipur (Salter & Sayer, 1986). The Indo–Chinese subspecies, *C. eldi siamensis,* is on the brink of extinction (Humphrey & Bain, 1990), with only

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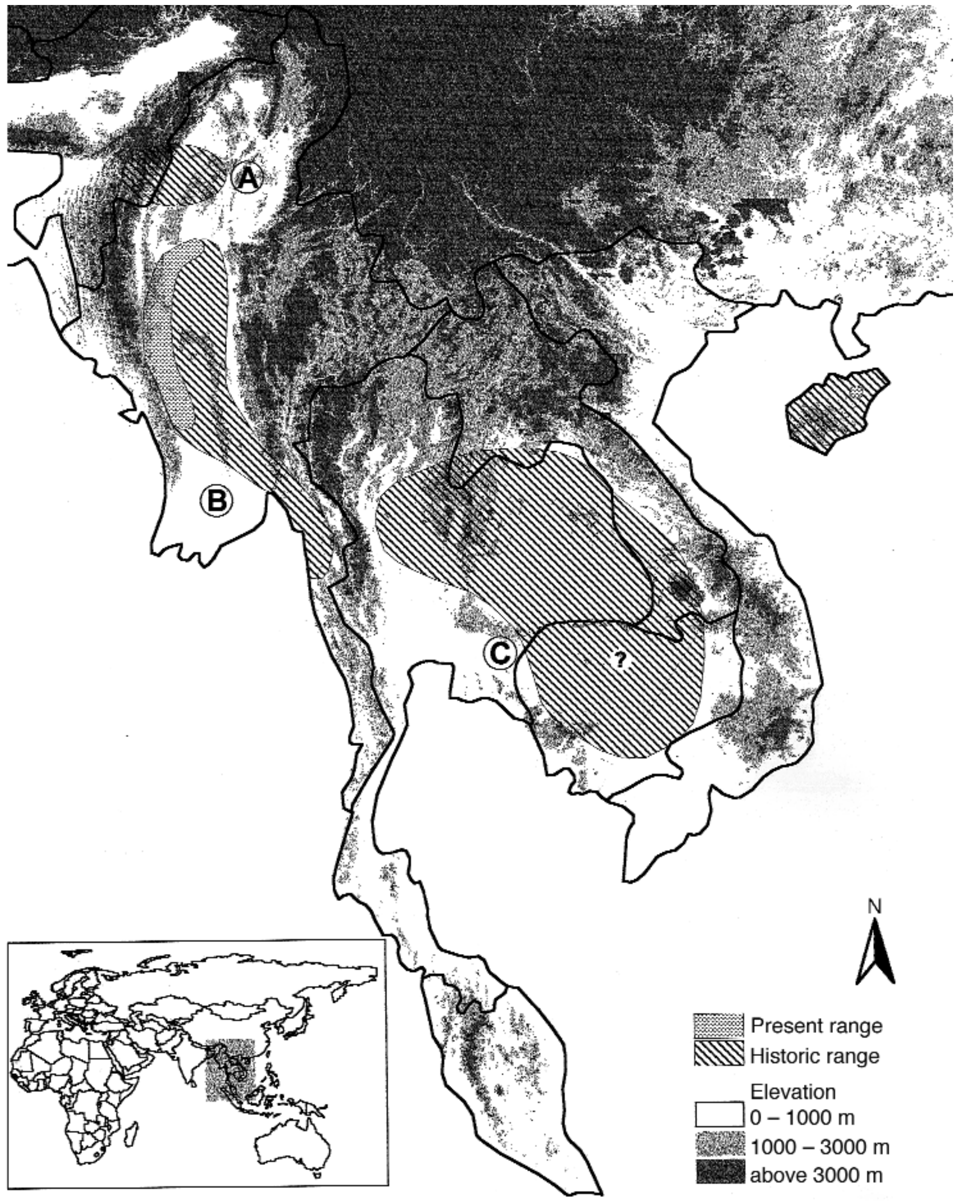

Fig. 1. Historical and present range of *Cervus eldi* in south-east Asia. Historical range, indicated by diagonal stripes, is derived from maps by Whitehead (1972) and shows the range of the three subspecies *C. eldi eldi* (A), *C. eldi thamin* (B) and *C. eldi siamensis* (C). The present range, indicated by stippling, is adapted from Tun Yin (1967) and Salter & Sayer (1986) and includes two semi-captive populations in India and Hainan Island, and a postulated (Humphrey & Bain, 1990) population in northern Cambodia (?).

one known population of approximately 150 individuals within a fenced reserve in Hainan (Song, 1996) and possibly a population in northern Cambodia (Humphrey & Bain, 1990). Populations of the third subspecies, *C. eldi thamin*, occur in scattered areas of central Myanmar (Tun Yin, 1967; Salter & Sayer, 1986). Within Myanmar, thamin were considered common throughout the 1940s, and their distribution was described as patchy, but abundant, in 1967 and 1986 (Tun Yin, 1967; Salter & Sayer, 1986).

Thamin are grazers and opportunistic browsers, who supplement their diet with wild fruit and cultivated crops, particularly rice (Lekagul & McNeely, 1977). Probably few pristine thamin habitats remain, and populations have been reported to occupy areas ranging from dry scrub and thorn forest to open deciduous forest (Salter & Sayer 1986; Wemmer, 1987). The least disturbed of these habitat types is deciduous forest.

Deciduous dipterocarp (indaing) forest is the most abundant forest type within south-east Asia (Rundel & Boonpragob, 1995). In 1990, Myanmar was approximately 50–58% forested, with 14% covered with some form of deciduous forest (UNEP, 1995; Achard & Estreguil, 1995). Rainfall, soil type and terrain account for most of the variation in forest types across south-east Asia (Richards, 1979; Rundel & Boonpragob, 1995). Although rainfall amounts are variable across the historical thamin range, the remaining thamin range in central Myanmar receives 100 cm of rain during the monsoon season (Salter & Sayer, 1986). Thamin are considered to occur only in deciduous forests (Tun Yin, 1967; Salter & Sayer, 1986; Humphrey & Bain, 1990), of which three types are found in this region; dipterocarp (indaing), dry (thandahat) and mixed deciduous (teak) (Stamp, 1925). All three types are confined to the region that annually receives 100–200 cm of rainfall (Stamp, 1925). Determining the abundance and distribution of these forest types is a focus of our research.

Myanmar has one of the highest proportions of forest cover in the Asian–Pacific region (UNEP, 1995). This forest inventory was based on NOAA AVHRR satellite data and it estimated cover of closed forest at 43.3% (29.33 million ha) of the country. Although forest cover, in general, is extensive in Myanmar, there may be significant losses of deciduous forest types. In Thailand, the only south-east Asian country for which reliable data are available, indaing forest has declined 45–60% over the last 20 years (Rundel & Boonpragob, 1995). Overall deforestation rates in Myanmar were estimated at one-third those of Thailand for 1980–1991 (Achard & Estreguil, 1995).

Fig. 2. Townships in Myanmar that have been reported to contain thamin in the last 30 years. The diagonally striped townships were listed as containing thamin by Tun Yin (1967), but did not contain thamin in 1992. The other townships were considered likely to contain thamin by Wildlife Department personnel based on questionnaires completed in 1992. Dark grey townships are those surveyed in 1997. All the townships surveyed in 1997 contained some evidence of thamin with the exception of Bundalin township (black area on map).

Table 1. Annual estimates of thamin abundance within Chatthin Wildlife Sanctuary based on line transect surveys conducted during the first week of April

	1983	1991	1992	1993	1994	1995	1996
Kilometers walked	81	94	76	73	81	174	87
Animals sighted	147	187	89	72	80	137	111
Density (deer/km^2)†	8.3	9.3	7.8	4.7	4.8	4.1	4.7

† Haynes estimator, Buckland *et al.* (1993).

The thamin population in Myanmar was estimated to be 4000 animals in the 1970s (Whitehead, 1972), but the first countrywide questionnaire distributed by the Wildlife Department in 1992 estimated that 2200 deer remained within Myanmar, with the largest population (>1200 deer) in Chatthin Wildlife Sanctuary (Myint Aung, 1994). This survey reported thamin in 28 townships, six townships fewer than reported in 1967 by Tun Yin (1967) (Fig. 2). Chatthin Wildlife Sanctuary (268 km^2) is composed of secondary indaing and mixed deciduous forest, and was originally established as a fuel reserve forest in 1941. Sight surveys for thamin along 65 km of line transects were conducted at Chatthin beginning in 1982 by the Food and Agriculture Organization (FAO: Salter & Sayer, 1986), and were repeated annually from 1992–1996 by forest rangers of the Wildlife Department (Table 1). These surveys estimated a 40% decline in thamin abundance since 1983.

Despite declines in the abundance of Eld's deer, both across its entire range and within Myanmar, no systematic field studies have been conducted. With respect to Myanmar, this is largely because it is one of the least externally-funded and internally-protected tropical countries in Asia (Balmford & Long, 1995). Our goals were to conduct a ground survey for thamin across the central plains of Myanmar, and to relate information on thamin abundance and distribution to maps of forest abundance and distribution. The result may serve both as a management guide for proposed protected areas, and to help determine landscape patterns that might explain the decline in the species.

METHODS

To determine the status of thamin and the extent of potential remaining habitat in central Myanmar, we conducted a series of field surveys and used the survey data to delineate forest stands on landcover maps derived from satellite imagery.

Thamin surveys

Surveys were conducted by Wildlife Department personnel in spring 1997. All 28 townships identified in 1992 as containing deer were contacted, and 24 townships were visited by survey teams. The survey team first conducted an interview with the Forest Department personnel responsible for the inventory and protection of all forest tracts within each township. On Forest Department maps, forestry personnel indicated the extent of forests within the township and which forest tracts contained thamin based on recent sightings. A second interview was conducted in each township with villagers who were considered knowledgeable about wildlife. Using the maps of forest cover produced during the first interview, the villagers were also asked to identify forest tracts that may contain thamin. The administrative office of each township provided 1997 census records on population size of humans and livestock, and estimated forest cover. Forestry personnel estimated the total number of thamin within their township.

As part of each township survey a field census was conducted, and consisted of at least one set of transects traversing a forested area. The first transect of each set traversed the forest tract, the second transect was laid out perpendicular to the first, and the third transect returned in the opposite compass direction of the first transect. When forest tracts were contiguous between adjoining townships, the information was combined prior to analysis (Table 2). Transect surveys for each township ranged from 9–236 km ($\bar{X}$ = 44 km), depending on the amount of forest cover. One walker was responsible for detecting tracks and faecal pellet groups along each transect, and the second walker concentrated on sighting deer. There was a significant correlation between the number of signs recorded and the number of deer observed (linear regression: $F = 4.48$, d.f. = 1,18, r^2 =0.20, P = 0.048). We used the number of signs detected along the transects, rather then the thamin sighting records, for an abundance index because these measures were less sensitive to variability in vegetation density across the habitats. The surveyors recorded total distance walked, and the distance walked in each habitat type, along each transect by counting their steps and converting that measure into meters. All forest types that covered >10% of the transect length are listed for the township (Table 2). For each thamin sighting the walker recorded the number of deer, their distance from the walker, and the angle of the sighting relative to the transect line (Buckland *et al.*, 1993). At Chatthin Wildlife Sanctuary (Kambalu and Kawlin townships) and Shwesettaw Wildlife Sanctuary (Minbu township) the transects are permanently marked and separated by 1.5 km.

The number of tracks and faecal pellet groups observed along a transect were combined to create a single abundance index. Both the number of signs and deer observations along a transect were divided by the number of kilometers walked. Estimates of population and livestock from census records were divided by the size of the township. Percent forest cover within each township was arcsin transformed before analysis, and abundance measures were log transformed if they were not normally distributed. Stepwise linear regression (backwards) and ANOVA were performed using SAS (SAS, 1987) on human census information that might be correlated with the abundance of thamin within a township. The presence/absence of thamin within forest tracts and landscape variables for each stand was examined using discriminant function analysis. The relationship between the number of thamin estimated by foresters and the number detected along the transects was tested using Pearson's correlation coefficients.

Landscape analyses and regional assessment

We used Arc/Info to digitize the outline of forest tracts, as drawn by Wildlife Department personnel on government township maps. We registered the final map to a landcover map produced from remote sensing analyses of Landsat TM imagery. To include the data from the field surveys for thamin in the digital map, we assigned

Table 2. Survey information for townships

Township	Area (km^2)	Population/ km^2	Livestock/ km	Forest (%)	Forest type[†]	Distance walked (km)	Distance sign/km	Number of deer/km
Thegon & Paungde	199	1258	522	23	In forest	11	1.1	0
Pyi	79	281	850	13	In forest	9	1.8	0
Minbu	167	846	413	48	Dry/In forest	37	0.19	0
Nga-Phae	131	281	214	68	Dry forest	53	0.3	0
Pwintbyu	122	1168	525	39	Dry forest	25	0.72	0
Salin	232	886	537	51	Dry forest	13	0.15	0
Mahlaing	111	595	657	25	Dry forest	17	0.05	0
Pauk & Pakokku	375	129	517	24	Dry/In forest	73	0.23	0.12
Nahtogyi	125	1493	1112	4	Dry forest	26	0.61	0
Ye-Sa-Kyo	100	2372	1118	12	Dry forest	27	0.63	0.03
Salingyi & Yinmabin	162	1511	1006	10	Dry forest	35	1.17	0.85
Wetlat	156	2047	785	6	In forest	20	1.65	0.3
Bundalin	107	1171	674	14	Dry forest	10	0	0
Depeyin	133	1019	507	48	Dry/In forest	29	0.4	0.03
Kane	336	406	234	52	Md/In forest	30	0.4	0.1
Khin-Oo	104	2507	1439	19	In forest	70	0.47	0.03
Yae-Oo	145	721	399	81	In forest	49	1	0
Tanse	186	765	406	49	In/Md forest	91	0.48	0
Kyunha	262	253	184	33	Md/In forest	15	2	0
Kambalu & Kawlin	531	632	405	42	In/Md forest	236	3.38	0.44

Townships were combined if forest tracts surveyed crossed township boundaries. Population, livestock and % forest values are from 1997 township census records. Forest type is dominant type in township, when mixed the more common is listed first. The townships are listed from south to north.
[†] In, indaing forest type; Md, mixed deciduous forest type

each forest polygon attributes for forest type and the presence or absence of thamin.

The present forest cover maps may be suited to assess trends in habitat fragmentation and conversion for southeast Asia (UNEP, 1995), but are not suitable for determining the remaining indaing and dry forest habitats in Myanmar. In the past, Landsat TM imagery has been successfully used for vegetation and landcover mapping (Lillesand & Kiefer, 1994), so we used this imagery to produce an accurate map of deciduous forest for central Myanmar. We obtained two sets of mosaicked, multi-spectral Landsat TM 4 images from the USGS EROS Data Center. Both sets of images were acquired in January 1989, the first covered the northern and central parts of our study region, while the second set covered the southern section of our study region. Images were geometrically corrected, projected to a UTM grid, and resampled using a nearest neighbour algorithm. Spatial resolution, the size of the picture elements (pixels), was 28.5 m × 28.5 m.

The classification of satellite imagery into a landcover map is usually performed with a set of target classes in mind that are described in a hierarchical classification system (Lillesand & Kiefer, 1994; ERDAS, 1997). Our landuse classification emphasized deciduous forest types, because we were interested in an accurate delineation of actual and potential habitat for thamin, specifically indaing and dry forest. Our landuse classes were:

- *Evergreen Forest*: Evergreen forests are characterized by diverse overstories of evergreen trees composed of several Dipterocarp species with sparse understories that may contain ferns or *Selaginella* (Stamp, 1925). In our study region, the forests are moist and are generally found only in mountainous areas, specifically along stream banks and ravines.
- *Mixed Deciduous Forest*: These are diverse forests that contain teak (*Tectona grandis*), along with *Xylia dolabriformis and Pterocarpus macrocarpus.* Different species of bamboo (*Bambosa* sp.) are common in the understory. Generally, the vegetation in this forest type is not as dense as in evergreen forests. Mixed deciduous forests are found in moist areas and along streams in central Myanmar, as well as on the slopes of the mountainous regions.
- *Indaing Forest*: In central Myanmar, indaing forest is found in sandy, flat terrain that seasonally floods and is dominated by *Dipterocarpus tuberculatus*, *Shorea obtusa, Terminalia tomentosa and Melanorrhoea usitata* (Stamp, 1925). These forests are open with sparse understories and abundant growth of grasses (Stamp, 1925). Indaing forest is commonly found in central Myanmar below an elevation of 1000 m (UNEP, 1995).
- *Dry Forest*: This category comprises dry deciduous forests and thorn forests, with widely spaced trees and little ground vegetation. Dry forest (thandahat) is characterized by *Tectona hamiltonii, Terminalia oliveri and Acacia catechu* (Stamp, 1925).
- *Grassland*: This category comprises seasonally flooded grasslands, but also pastures, and lwins in the open indaing forests.
- *Agriculture*: This category comprises areas used in cultivation, including crops, degraded shrublands, or pastures.
- *Barren*: This category comprises rocky outcrops, sandbanks in large rivers, developed lands, and heavily eroded areas that were previously degraded by agriculture and logging.
- *Water*: This category comprises lakes, reservoirs and rivers.

Indaing and dry forest are restricted to the low elevation areas (UNEP, 1995) and thamin are not reported in townships whose average elevation is above 1000 m. In order to reduce topographic effects that tend to complicate the differentiation of forest types in regions with strong topographic relief (Lillesand & Kiefer, 1994; ERDAS, 1997), areas above 1000 m were removed from our images using digital elevation data from the Digital Charts of the World data set (ESRI, 1993).

Using ERDAS Imagine image processing software, we applied ISODATA clustering algorithms on bands 3, 4 and 5 of the Landsat TM images to produce 50 spectral clusters in the initial classification (ERDAS, 1997). Each of the 50 clusters was assigned to one of our landcover categories based on one investigator's (W.J.M.) knowledge of the country. In 1997, two investigators (W.J.M. and P.L.) collected ground-truth information at Chatthin Wildlife Sanctuary, Alaungdaw Kathapa National Park and the intervening roadways, to evaluate the accuracy of the landcover map. We used Global Positioning Systems to determine the exact geographic location of the reference points. After refining the classification, we calculated the overall accuracy of our landcover map using information from reference points that were collected during the previous site visit. Overall accuracy of the final classification was 79 %, with high accuracies for indaing forest (85 %).

The landcover classification of central Myanmar was overlaid with a map of the forest stands surveyed for thamin. Using these digitized forest polygons and the landcover map, we determined the % cover of each landcover type encompassed by the polygon. To facilitate landscape analyses of thamin habitats, we removed all landcover categories other than indaing or dry forest, and resampled the image to a spatial resolution of 5 km × 5 km. During resampling, each cell in the new raster map that comprised at least 30 % of either indaing or dry forest was classified accordingly. Therefore, the smallest patches of indaing or dry forest on the resampled map are at least 25 km^2 and are covered by no less than 30 % of either dry or indaing forest. The minimum size of the sampling unit was chosen because a current radio-tracking study of thamin at Chatthin Wildlife Sanctuary revealed a relatively large home range (6 km^2; W. J. McShea, pers. comm.) indicating the deer require large areas, and anecdotal evidence of deforestation since the Landsat images were taken in 1989 led us to believe many of the smaller patches no longer existed.

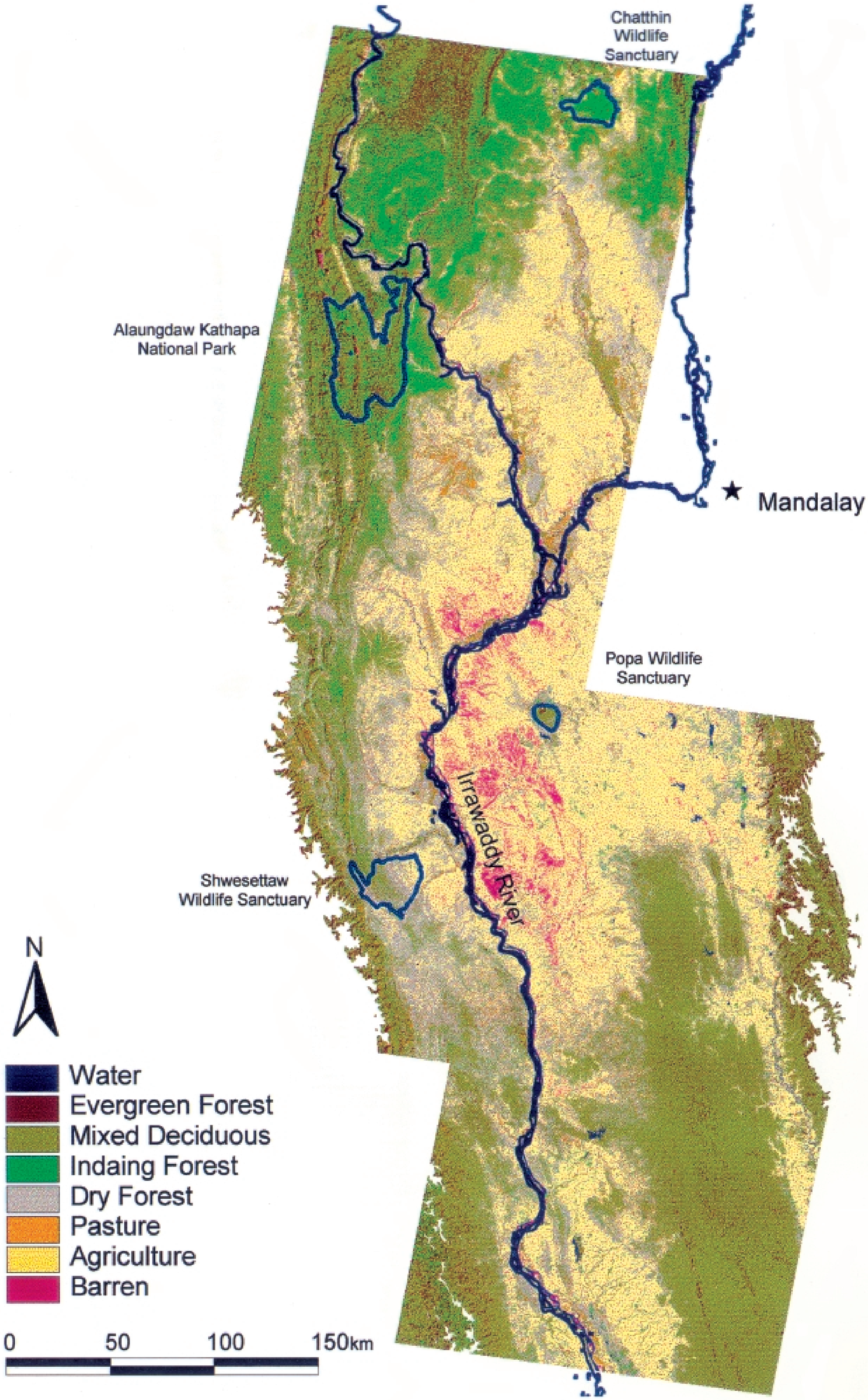

Fig. 3. A landcover map based on five 1989 Landsat TM images. The boundaries (in blue) of the four established protected areas within the study area are shown.

We used the FRAGSTATS (McGarigal & Marks, 1995) program to quantify landscape characteristics and patterns of indaing and dry forest patches (see Appendix). Patches are defined as a group of pixels that are of one forest type, either indaing or dry forest, and that are connected by at least one corner or one other pixel. We were interested in the spatial relationships between patches, their configuration in the landscape and what role these landscape characteristics play in the distribution of thamin. Based on the results from our landscape analyses, we predicted where thamin are likely to occur and which areas may have suitable habitat for re-introduction and protection. We standardized the results from FRAGSTATS to a mean of zero and a standard deviation of ±1. Using the digitized maps from field and township surveys, we identified patches that were surveyed for thamin (n = 63). In a discriminant function analysis we used this set of patches as training data to identify the linear combinations of variables that best separated patches with thamin from patches without thamin. We then used the identified discriminant functions to classify all unsurveyed patches into patches that either were likely or unlikely to support thamin populations.

Table 3. Landuse and forest type classification of study area based on five 1989 Landsat TM images

Land class	Area (km^2)	Land cover (%)
Water	1230	1
Barren	1988	1.6
Agriculture	41 323	33.5
Grassland	4269	3.5
Forest	74 606	60.4
Dry	19 224	15.6 (25.8)†
Indaing	8691	07 (11.6)†
Mixed deciduous (teak)	43 603	35.3 (58.4)†
Evergreen	3088	2.5 (4.1)†
Total	123 416	

† Percentage of forest cover.

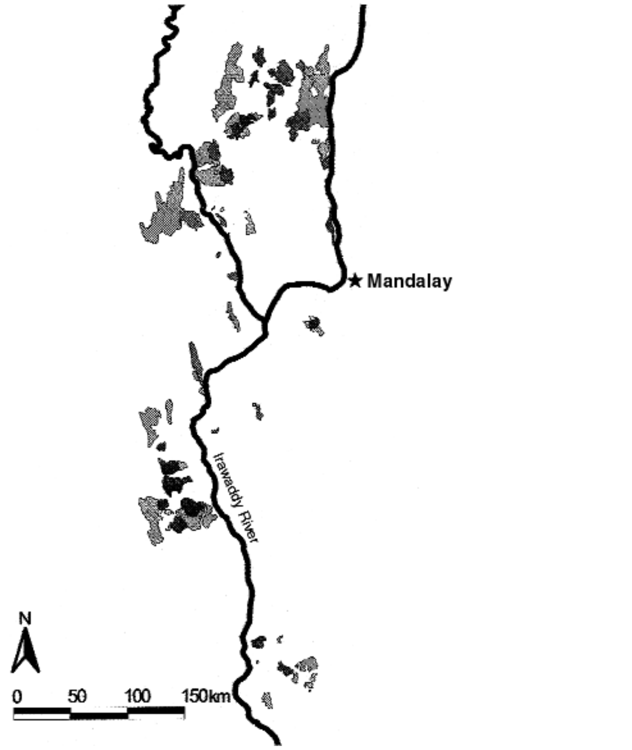

Fig. 4. The forest stands surveyed by Wildlife Department personnel in spring 1997. The stands containing thamin are indicated in dark grey.

RESULTS

The classified landcover map incorporated 123 415 km^2 of the central plains of Myanmar (Fig. 3). Forest cover encompassed 60% of the area (Table 3). Of the three deciduous forest types preferred by thamin, mixed deciduous (teak) forest was the most abundant (35%), followed by dry forest (16%) and indaing forest (7%). Using the resampled map that included only large (> 25 km^2) forest tracts of predominantly (> 30 %) indaing or dry forest, resulted in a lower estimate of dry forest (7%), but a similar estimate for indaing forest (8%).

Surveys

The 24 townships were surveyed along 876 km of transects (see Table 2). Sign of thamin (i.e. faecal pellet groups or tracks) were observed in 23 townships, with actual sightings of deer in 12 townships (Fig. 4). Within forest stands that contained thamin, the number of sign/km of transect was not significantly correlated with human population density (partial F = 0.02, d.f. = 1,18, P > 0.1), livestock density (partial F = 1.17, d.f. = 1,18, P > 0.1), or % forest cover (partial F= 0.23, d.f. = 1,18, P > 0.1).

For 16 townships we have an estimate of thamin numbers obtained during the interview with local foresters. The number of deer signs detected/km of transect was correlated with the number of deer estimated by the township foresters during interviews (r = 0.69, n = 16, P < 0.002). However, the highest estimate for a township (Kambalu estimate = 1590) was more than 3 standard deviations (SD) above the other townships and when this estimate is deleted there is no significant correlation between forester estimates and estimates based on the actual transects (r = –0.12, n = 15, P >0.1).

Thamin were not evenly distributed across forest types (ANOVA F = 3.16, d.f. = 3,16, P = 0.05). The highest density of sign/km transect was observed in indaing/mixed deciduous forest ($\bar{X}$ = 1.56 (± 1.42) SD) and indaing forest ($\bar{X}$ = 1.24 (± 0.59) SD), while the indaing/dry forest ($\bar{X}$ = 0.27 (± 0.11) SD) and dry forest ($\bar{X}$ = 0.45 (± 0.4) SD) types contained fewer deer.

Landscape analyses

There were 63 forest stands categorized by the field teams that occurred within the boundaries of the landcover map. We used the classified landcover map to determine forest composition within these stands. Forest stands with thamin contained more indaing/dry forest, more agriculture and less mixed deciduous forest then forest stands that did not have thamin (discriminant function analysis, $F = 8.04$, d.f. = 3, 63, $P < 0.0001$, $r^2 = 0.15$).

The landcover map was resampled to contain only stands of indaing or dry forest greater than 25 km² in size (Fig. 5). We found 9166 km² of dry forest distributed within 254 stands and 9532 km² of indaing forest distributed in 120 stands. A stepwise discriminate function analysis (backwards) revealed that stands containing thamin had a larger core area than stands that did not contain thamin (Table 4: $F = 4.0$, d.f. = 1,62, $r^2 = 0.06$, $P = 0.05$). If dry and indaing forest landscape variables were analyzed separately, there were no significant landscape predictors for dry forest stands, but the size of the core area was highly significant for stands of indaing forest (Table 4: $F = 15.8$, d.f. = 1,21, $r^2 = 0.42$, $P = 0.0007$).

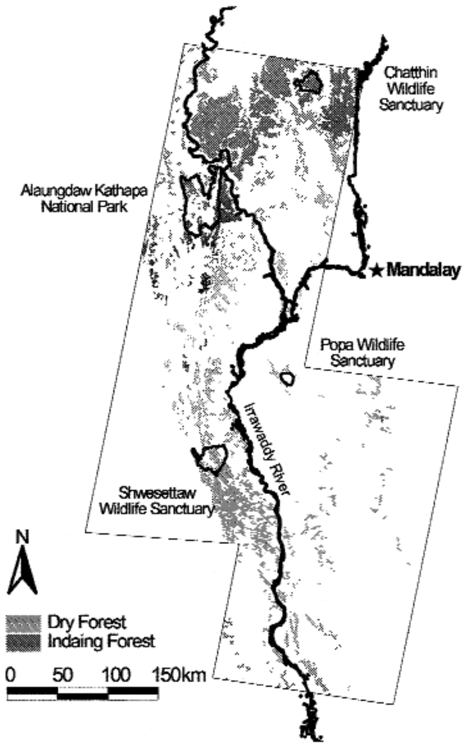

Fig. 5. Forest stands greater than 25 km² and containing at least 30% dry or indaing forest types based on a resampling of the landcover map shown in Fig. 3. The boundaries of the four established protected areas within the study area are outlined.

The landscape discriminant functions that differentiated between thamin and non-thamin stands were used to predict which of the unsurveyed stands fit the criteria established to contain thamin (Table 4). For the function derived from both dry and indaing forest ($P = 0.05$), 14 out of 213 unsurveyed stands have a core area sufficient in size to potentially contain a thamin population. For the function derived for indaing forest only ($P = 0.0007$), none of the 97 unsurveyed stands possessed a core area of sufficient size to support a thamin population.

DISCUSSION

We found thamin only in the north-east fringe of the geographic range identified by Salter & Sayer (1986). This fringe encompasses all the remaining large tracts of dry and indaing forest within central Myanmar. The persistence of peripheral populations supports the pattern of range collapse observed for other species of large vertebrates (Lomolino & Channell, 1995, 1998). They found that species experiencing a range collapse persist not at the centre of their former range, but along the periphery in remnant populations. They attribute the

Table 4. Results of discriminant function analysis (DFA) for landscape attributes of forest patches derived from reclassification of Landsat images into dry and indaing forest patches

Landscape variable†	Forest patches					
	All		Dry forest		Indaing forest	
	Partial r^2	F	Partial r^2	F	Partial r^2	F
Area	0.016	0.966	0.029	1.036	0.066	1.126
Fractile dimension	0.040	2.386	0.045	1.613	0.103	1.848
Shape index	0.023	1.355	0.038	1.348	0.059	1.004
Core area	0.047	2.791	0.045	1.622	0.238	5.002‡
Nearest neighbour distance	0.007	0.403	0.048	1.723	0.067	1.856
Number of core areas	0.013	0.740	0.024	0.859	0.014	0.230
Surveyed patches						
Number of patches	64		41		23	
Number correctly classified using DFA	34		18		21	
Unsurveyed patches						
Number of patches	310		213		97	
Number potentially suitable using DFA	14		25		0	

Partial r^2 and F values are given for initial loading of variables prior to stepwise DFA (backwards) Core area of indaing forest patches was the only significant landscape variable according to the stepwise DFA (see results). Classification scores using DFA are given for each subset of survey data, as well as the number of potential thamin patches using the DFA to predict suitability of unsurveyed patches.

† For explanation of landscape variables see Appendix.

‡ $P < 0.05$.

persistence of these populations to their isolation from decimating forces and the general characteristics of isolated populations, which may make them more resilient to change. The pattern observed with thamin is probably less due to these sites being isolated islands, but rather to the sites constituting the last large tracts of forest on the edge of an advancing tide of human cultivation.

The decimating forces (Lomolino & Channell, 1995) at work in the decline of thamin are probably anthropogenic disturbances. Agricultural subsidies and policies that encourage deforestation are a primary concern throughout south-east Asia (Braatz *et al*., 1992), and the Myanmar government views increased rice production as a major potential export. The central plain of Myanmar is shaped like a bowl, with mountains to the north, east and west providing natural barriers to the cultivation of rice (Fig. 1). Indaing and dry forests persist along the edges of this bowl (Fig. 3), but as advances in human cultivation enable farmers to push into the surrounding hills, the remaining forest is removed. Large portions of Myanmar are still forested (> 55%: Achard & Estreguil, 1995), but the forest type present in these mountains does not appear to be suitable for sustaining viable populations of thamin. Four protected areas are situated within the range of thamin and all are forested, but only Chatthin Wildlife Sanctuary contains significant amounts of indaing forest, and only Shwessetaw Wildlife Sanctuary contains dry forest.

The loss of forest habitat is compounded by the lack of thamin in small forest patches. A large core area was the only landscape measure that was significant in the discriminant function describing deciduous forest patches that contained thamin. The loss of deer from small patches may be due to reduced productivity within these deciduous forest patches. The prolonged dry season in central Myanmar produces a ‘nutrient winter’ during the hot–dry season (March–May), after the crops have been harvested but before the monsoon rains begin. In savanna ecosystems of West Africa, productivity is lowest during the hot–dry season, and bovids focussed on grass productivity following intermittent fires (Schuette *et al*., 1998). Indaing forest is fire-adapted (Stott, 1986; Rundel & Boonpragob, 1995) and man-made fires are common during the hot–dry season to clear crops and to stimulate the growth of grass for livestock.

Indaing forest also responds to fire with a vigorous growth of grasses in the understory (Rundel & Boonpragob, 1995). Folk wisdom in the villages asserts that a strong fire, one capable of generating grass regeneration, is not possible in either dry or indaing forest that has been degraded. A pattern of forest degradation that progresses from select logging and fuel-wood removal, to intensive cultivation/grazing and decreased fire interval, has been described for Thailand (Blasco, 1983) and applies to Myanmar. With fuel-wood consumption being a major cause of deforestation in this region (Braatz *et al*., 1992), the degraded habitat that results from wood extraction and overgrazing along the periphery of each forest stand may not generate sufficient fires to trigger grass regeneration.

As with domestic livestock, thamin are primarily grazers (Lekagul & McNeely, 1977) and may depend on the pulse in grass productivity generated by fires in intact indaing forests. Fire as a wildlife management tool has been proposed for other open forest/savanna ecosystems in Nepal (Dinerstein, 1979, 1987). Based on the population estimates for the townships surveyed, no forests in the study area were immune to the influence of farmers. Larger forest stands may provide enough isolation from the daily scouring for fuel-wood and fodder to generate grass-producing fires during the dry season. It may not be necessary to restrict all access to these wildlife sanctuaries, but use should be managed, particularly along the sanctuary boundaries. Saberwal (1996) found that moderate livestock grazing in Indian parks was compatible with conservation needs, and advocated working with villages in developing wise use of limited sanctuary resources.

Our landuse classification is based on a 1989 Landsat image and how much forest has been lost since that time is conjecture. Human population growth and associated environmental demands have been mounting in Myanmar, with a major focus on expanding rice production to generate export capital. It is our impression that the loss of forest since 1989 has concentrated on the smaller patches embedded within the agricultural matrix. Larger patches of forest still persist, but few of these large patches exist within the present protected area framework (Fig. 5).

Within the study area, there were few unsurveyed stands of dry or indaing forest that could potentially contain thamin. However, the existing reserves encompass only small portions of the largest forest tracts. Our first recommendation would be to expand existing reserves in the northern townships to incorporate as much remaining indaing forest as possible. This may be done by enlarging the gazetted reserves of Chatthin Wildlife Sanctuary and Alaungdaw Kathapa National Park, or by establishing a new sanctuary between these two reserves in the Maha-myaing region along the northern reaches of the Chindwin River. The last remaining large dry forest stands exist around the Shwesettaw Sanctuary in the southern part of the study area, although this forest type did not possess the densities of thamin observed in indaing forest. Our second recommendation would be to clarify the role of fire in maintaining both indaing and thamin populations. Our third recommendation is that thamin conservation is not incompatible with farming activities, but there needs to be a recognition that the remaining dry and indaing forest serve a function within these rural communities both for livestock and thamin. Conservation methods that serve to prevent the degradation of these habitats should be a priority.

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APPENDIX

Landscape metrics for analyses of differences in patch and landscape characteristics between forests with and without thamin. Adapted from McGarigal & Marks (1995).

Landscape metric	Description	Formula[†]
Area	Area of patch is dependent on the size of pixels and is calculated in hectares.	
Fractal dimension	Measurement of complexity of the perimeters of patches. Fractal dimensions in FRAGSTATS are treated as perimeter-area relations.	$FRACT = \frac{2\text{In}\left(0.25 p_{y}\right)}{\text{In} a_{ij}}$
Core area	Core area is the area that is more than 1 pixel away from the patch perimeter and is calculated in hectares.	
Number of core areas	If a patch has no area that is more than 1 pixel away from the perimeter, this number equals zero. Otherwise the number of core areas for a patch equals the number of disjunct areas that are more than 1 pixel away from the perimeter.	
Nearest neighbour distance	Distance to the nearest patch of the same type. Measured as shortest possible distance between edges in metres.	
Shape index	Compares the shape of a patch to a circle and increases in value as patches become more irregular in shape.	$SHAPE = \frac{0.25 p_{y}}{\sqrt{a_{ii}}}$

[†] Equation symbols: p_{ij}, perimeter of patch *ij*, measured in metres; a_{ij}, area of patch *ij*, measured in hectares.