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CHAPTER SEVENTEEN

Habitat suitability analysis using logistic regression and GIS to outline potential areas for conservation of the Grey Wolf (*Canis lupus*)

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17.1 INTRODUCTION

Distribution patterns of large carnivores are strongly influenced by environmental discontinuity, human persecutions and other human activities. Their distribution can be regulated by extrinsic factors such as: weather conditions, food supply, vegetation and human disturbance in the landscape (Schamberger and O'Neil, 1986; Yalden, 1993). Understanding why similar regions show different distribution patterns could also be explained by historical reasons of animal–human conflicts. Large-bodied predators, particularly the Grey Wolf, have been persecuted for animal damage control (Fritts and Mech, 1981), due to their economic value – e.g. fur – and out of fear (Boitani, 1996). Moreover, the fact that in terrestrial systems, large carnivores are principally limited to a few species of mammals occurring in low density populations[1] makes this group more susceptible to human perturbation (Yalden, 1993).

Modelling the relationships between animals and their biotic and physical environment has been used in planning studies and it provides a framework around which habitat information can be structured for decision-making. These animal–habitat interactions provide a consistent basis for impact assessment, mitigation, baseline, conservation and monitoring studies (USFWS, 1980; Lancia *et al.*, 1986; Morrison *et al.*, 1992). Such models, based on the concept of habitat, which is defined as the ability of the habitat to provide life requisites (Schamberger and O'Neil, 1986), may yield biological insight to explain the distribution of wolves and evaluate land-management activities.

In this context, the aim of the paper is to analyze the distribution of the Grey Wolf in the Nearctic zoological realm by means of GIS and multivariate statistical modelling. We first predict the probability of wolf-occurrence used as a proxy of habitat quality.

Secondly, the model is validated on an independent set of samples and classification error rates are estimated. Finally, the overall model output in the form of a probability map is used for selecting wolf-habitat types. These are compared with information regarding protected areas to allocate potential regions for conservation or reintroduction. The approach followed here is practical, allowing one to make statistical inferences while yielding biological insight, and it summarizes and predicts the occurrence of a single species used as surrogate of habitat quality. The results are placed within the context of human impact on a habitat-endangered species with the emphasis on predator–human relationships.

17.2 BACKGROUND

17.2.1 Development of a conceptual framework

It has been proposed (Cousins, 1990) that the larger ecological unit that can be made by ecological processes is the food web of the top predator. Indeed, it is suggested that this food web structure is the physical representation of the ecosystem object as opposed to the traditional ecosystem concept of Lindeman (1942). The top predator's territory defines the limits of these ecological units which include all organisms found within its territorial boundary. In a system with no human intervention, the top predator of the food chain is normally the largest species that can predate the largest prey species. They have prey but not predators (Brian and Cohen, 1984). These units have been named by Cousins (1990) 'Ecosystem Tropic Modules' (ETMs). The ETM is a countable object that can be mapped since it has spatial attributes. More broadly the ETMs can be seen as units which retain the food web dynamics and biodiversity of a whole ecosystem.

Here we propose that modelling the relationships of environmental attributes and the size of the ETM could be used to define potentially suitable areas for protection with different levels of human intervention. For this study we made some simplifying assumptions when building the wolf-habitat suitability model:

1 The probability of wolf presence was used as a proxy of habitat quality. It is assumed that there is a highest probability of finding the species in areas that satisfy the species' life requirements (Fritts and Mech, 1981).
2 Wolf packs have non-overlapping home range (Fritts and Mech, 1981), and they use it evenly.
3 Similar home range size was assumed for different habitat types.
4 The geographical range of the species is spatially discontinuous. Home ranges are not uniformly distributed in space, but rather they tend to be clustered together in regions of suitable habitat (Fritts and Mech, 1981). Thus the geographical range is viewed as clusters of ETM defined by wolf metapopulations.

17.2.2 Study area and distribution of the species

The study area was defined by the former wolf geographical range over the Nearctic realm according to the Udvardy classification (Udvardy, 1975). It comprises Greenland and North America without the southern tip of Florida (the Everglades). In this realm the wolf was found, except for the southern part of the USA, where the Red Wolf (*Canis* *rufus*) was present. The present wolf range has been considerably reduced, mainly in the conterminous United States and Mexico (Nowak, 1981).

The Grey Wolf has the greatest natural range of any living terrestrial mammal other than man. It was found in almost all habitats of the northern hemisphere except equatorial tropical forests. Wolves are habitat generalists. They occupy habitats such as: tundra, taiga, subalpine, mixed and hardwood forests, steppes, grasslands, chaparral and deserts (Nowak, 1981). The study of the species and its habitat has also been undertaken in the Palearctic and Indo-Malayan realms (Europe, Asia and the Arabian peninsula) for comprehension of the wolf-habitat relationships over its global geographical range (De La Ville, 1997).

17.3 METHODS AND PROCEDURE

17.3.1 Construction of the digital database

The selection of the variables and their assemblage into the GIS are the most expensive and time-consuming steps for spatial analysis. They generally involve tailoring databases of different storage format, quality and resolution. The choice is governed largely by the available budget and the purpose of the study. Despite these constraints, GIS users must be sure that the resulting database is as free as possible from error. The GIS software application used here was ARC/INFO version 7.0.4 on a UNIX platform for storage, editing and handling the GIS layers, and the PC version 3.4 for digitizing (ESRI, 1994).

Source materials of the wolf distribution included national and regional maps published in journal and literature references (for a review showing the sources used, see De La Ville, 1997). It also included information from the IUCN-SSC Wolf Specialist Group and the International Wolf Center. The source for the habitat-descriptors included digital information in map form with different format types. Some of the sources were themselves compilations and others were based on source data. The most reliable and most recent source material was used, but in some instances older material was more accurate than the newer sources. The overall result was a hybrid database which emphasized spatial information rather than temporal uniformity.

A set of nine habitat variables were selected and layers were built using a series of GIS operations. The dependent variable was recorded in binary format as wolf-presence or absence. The borders of the predator distribution were digitized at 1:1 000 000 scale using the Digital Chart of the World (DCW) as contour maps (ESRI, 1991). Information on elevation and road networks were also obtained from the DCW. The unequal interval classes for elevation were transformed into a distribution frequency for statistical analysis in order to avoid using this attribute as a dummy variable. From the road network a layer data regarding road density (km/sq. km) was estimated using GIS capabilities.

Information regarding population of cities over 200 000 inhabitants was collected (UNEP, 1985) and transformed into a sphere of influence according to population size. Buffers were generated around each point defining the distance according to the Central Place theory (Christaller, 1930 in Waugh, 1995). The buffer's area varies in size from a small village to a primate city and forms a link in urban hierarchy.

The land-cover data is the Wilson and Henderson-Sellers classification (1985) recorded on two separate arrays as primary and secondary land-cover types. The original classification scheme included 53 vegetation classes based on physiognomy, density and seasonal variation. The classes were broken down into 17 components and each cell was assigned the absolute percentage of cover for modelling purposes. The components were then regrouped on the basis of physiognomy and agricultural areas, for a total of four categories: percentage of cover for *woody* (trees and shrubs) and *herbaceous* (grass, crop and tundra) elements in *natural* and *modified* areas. The original classification scheme was also used for generating the land-cover types within the wolf-suitable habitat.

For climatic characterization the data set used was the IIASA database. It provides a global terrestrial grid of 0.5 × 0.5 degree lat./long compiled from weather records from different sources (Leemans and Cramer, 1991). Total annual rainfall and the average maximum temperature were used as climatic variables.

A digital dataset of protected areas was obtained from the World Conservation Monitoring Centre (WCMC) in ARC/INFO format with region topology. This attribute was not included in the model. It was used to compare the wolf-suitability map and land-cover types with current areas under management. This dataset is classified according to IUCN (1994) into six categories according to primary management objectives.

The analysis was carried out in raster format with a cell size of 10 × 10 km. This is a trade-off between the average wolf pack territory[2] which defines the size of the ETMs, the original resolution of the data set and CPU-time. All layers and grids were analyzed using the Lambert Azimuthal equal area projection. A cell size of 100 sq. km generated a bounding rectangle of 810 rows and 1 540 columns for a total of 1 247 400 cells, of which 184 640 were contained within the study area.

17.3.2 Analytical design

The nine GIS layers (covariates) and the wolf-distribution layer (dependent variable) were subjected to the fieldwork operation through systematic sampling in ARC/INFO. It was assumed that only one potential observation per location was available. Thus the amount of replication at any site was not considered here as a design parameter. The sample data can be depicted as two-way table or matrix with observations at each location (rows) and variables (layers) or cell descriptors as columns. Systematic sampling schemes were carried out, and spatial autocorrelation using Moran's I coefficient was tested for the third, fifth and seventh-order lag (30, 50 and 70 km). The data matrix selected was input into SPSS version 6.1 for statistical analysis (SPSS, 1994).

One of the objectives of this study was to test the relationship between a dichotomous dependent variable (presence/absence) and independent environmental variables in order to build a model that would best describe in terms of probability the quality of the wolf habitat. Two related, and yet conceptually quite different, techniques could have been applied: logistic regression and discriminant analysis. However, the non-linear logistic regression was selected because the independent variables did not satisfy the assumptions of multivariate normality and equal covariance–variance matrix necessary for discriminant analysis (Cox and Snell, 1970). Logistic regression has been used previously for analyzing anthropogenic deforestation in Honduras (Ludeke *et al.*, 1990), modelling kangaroo presence/absence data (Walker, 1990), the distribution of the Mt. Graham red squirrel (Pereira and Itami, 1991) and interpreting bird atlas data (Osborne and Tigar, 1992).

The parameters of the wolf-habitat suitability model were estimated with the maximum likelihood method, using a forward stepwise variable selection. It is important to recognize that this method does not give the best selection of variables in an absolute sense, just the best statistical model that fits the data under a particular set of conditions.

The contribution of each variable to the model was estimated using the partial correlation coefficient (R). The validation of the model output was carried out using a split sample test, where the model is obtained from one part of the dataset and calibrated on another part (Pereira and Itami, 1991). The model equation was estimated on 80% (5 898 cells) of the data and model validation was carried out on the remaining 20% (1 441 cells). The classification error rates were determined from the percentage of correct predictions when the model predicts presence and the wolf is actually absent (error type I) and model prediction on the wolf absence when it was observed as present (error type II). They were estimated by selecting at each cut-off of probability value the number of cells correctly and wrongly predicted with wolf-presence and absence. Changing the classification rules allowed one to group cells to the left of a given point as unsuitable habitat (wolf-absence), while cells located to the right were assigned as suitable (wolf-presence). The classification rule for an optimum cut-off value, for defining suitable or unsuitable habitat, was chosen as the probability with its most successes and lowest failure.

It should be mentioned that areas where wolf-occurrence was unknown (see Figure 17.3a in the colour section), were not included for building the model. Instead these cells were used for model prediction. The model equation was input into ARC/INFO and the result was a map of continuous probability. It was sliced into 10 discrete probability intervals, from 0 to 1.

17.4 RESULTS AND DISCUSSION

17.4.1 Spatial autocorrelation and sampling scheme design

Moran's I autocorrelation index at the third order lag (each 30 km) for each layer was close to unity (~ 0.99). Large values of the coefficient ($I > 0$) mean that clustered cells have strong spatial similarities on their attributes (Cliff and Ord, 1981). For the fifth and seven order it dropped close to 0, ranging from 0.11 to 0.23. For the seventh order the maximum value was 0.15. The sample cells lagged at fifth and seventh order were independent and uncorrelated. Thus, the systematic sampling design at fifth-order lag, each 50 km, was applied in both directions (Easting and Northing).

17.4.2 Wolf habitat suitability model

The final coefficients and statistics for the best model are summarised in Table 17.1. From the original 9 variables the only one removed from the model was total annual rainfall (its residual chi-square for the coefficient β was greater than 0.05 at 95% confidence level). The rest of the variables met the criterion for remaining in the model, with β differing from 0 at 95% confidence level. Given the coefficients of β in Table 17.1, the logistic model equation for the probability of the event occurring, i.e. suitable habitat, can be written as:

$$\text{Prob}(\textit{suitable\_habitat}) = \frac{1}{1 + e^{-z}} \tag{17.1}$$

where

$$z = 1.10 - 4.19 \times \textit{road\_den} - 0.36 \times \textit{woody}(m) - 0.10 \times \textit{hum\_den} - 0.06 \times \textit{grass}(m) + 0.02 \times \textit{grass}(n) + 0.07 \times \textit{woody}(n) - 0.05 \times \textit{max\_tmp} + 0.01 \times \textit{elev} \tag{17.2}$$

Table 17.1 Final coefficients and statistics for the best model (*m* = modified areas, *n* = natural areas).

Variable	β	Significance level	R
Constant	1.10	–	–
road_den	−4.19	0	−0.13
woody (m)	−0.36	0	−0.13
hum_den	−0.10	0	−0.11
grass (m)	−0.06	0	−0.10
grass (n)	0.02	0	−0.10
woody (n)	0.07	0	0.07
max_tmp	−0.05	0	−0.06
elev	0.01	0.007	0.03

By looking at Table 17.1, it is possible to see that the values of the statistic R are quite similar for the first 7 covariates. This indicates that each variable has a similar partial contribution to the model. However, there is one group positively affecting the probability of the occurring event, while another shows an opposite effect. Variables with positive values for the statistic R indicate that, as they increase, the likelihood of finding a suitable habitat for the species also increases. For negative values, the opposite is true. According to the results shown in Table 17.1, herbaceous elements in natural areas have a positive effect for defining suitable habitat for wolves. This result would seem paradoxical, since open landscapes, i.e. tundra and steppes, offer low protection for wolves from man – e.g. hunting from aircraft (Bibikov, 1994). However, it should be noted that this part of the study area is the least perturbed by human activities. On the contrary, as was expected, the presence of woody elements in natural areas is likely to increase the likelihood of finding suitable habitat, since wolves are less vulnerable in forests and woodlands.

The occurrence of extremely low maximum temperatures, on the other hand, is a factor that determines low habitat-quality and therefore limits the probability of finding wolves (Marquard-Petersen, 1986). The elevation variable has a positive and the smallest contribution to the model output. The highest value for this variable corresponds to the lowest elevation class (0–340 m.a.s.l.). Therefore, high-quality habitat can also be defined by low elevation ranges.

Descriptors used as a measure of human impact (road and human density, woody and herbaceous elements in modified areas) have a negative effect on the species' habitat quality. Human activities, i.e. industrial, agricultural and residential development, tend to modify natural areas, and therefore pose a threat to wildlife and their habitats. Although some areas in North America retain significant and pristine natural habitats, these stocks are nothing like as large as they once were.

The model classification for observed and predicted data on the set of training cells gave an overall percentage of correct prediction of 91.35% at 0.5 probability value. Cells with values assigned as non-suitable habitat (probability of the event not occurring) were correctly predicted with less exactitude (83.23%) than cells allocated as suitable habitat (96.74%). These results give a percentage of error type I of 16.77% (cells predicted with

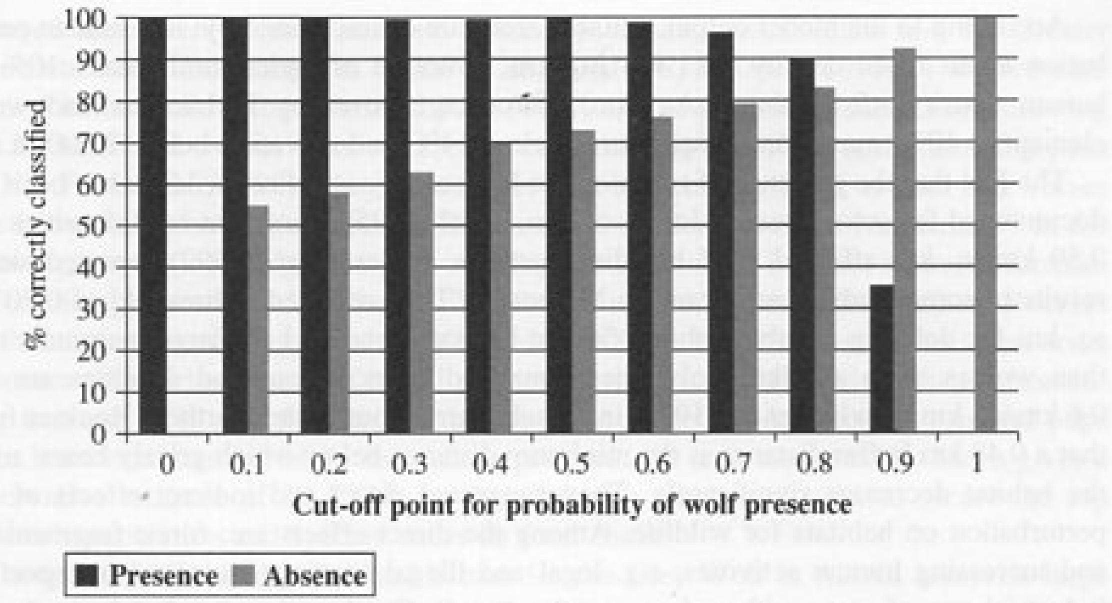

Figure 17.1 Model validation: classification error rates on the 20% of the original sample data in the Nearctic realm (NEA).

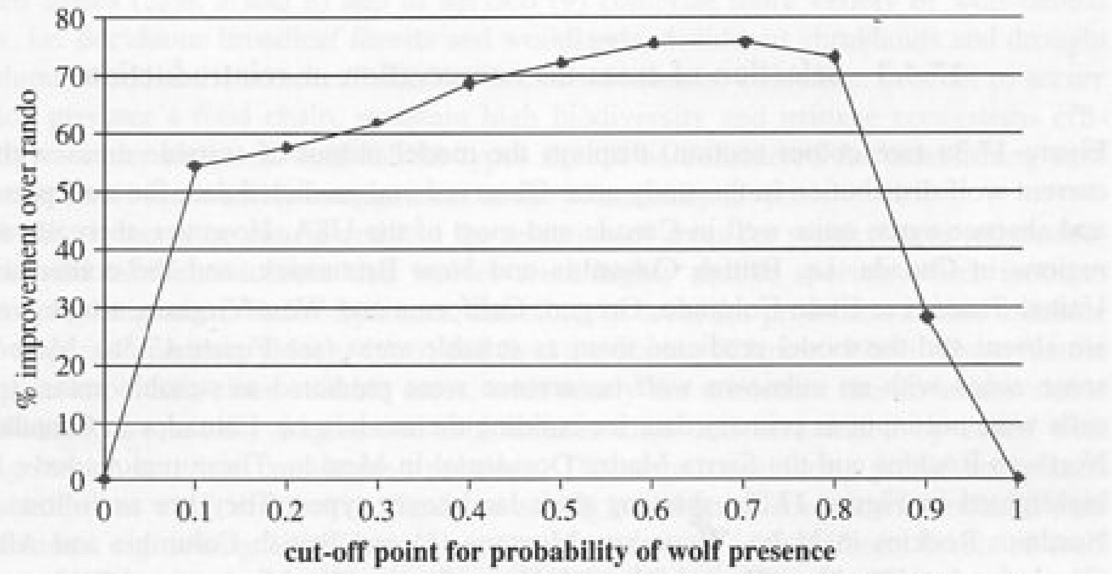

Figure 17.2 Improvement over a random set of samples for classification rules at different cut-off probability values.

wolf-presence when it is actually absent), and error type II of 3.26% (cells predicted with wolf-absence when it is actually present).

Figures 17.1 and 17.2 display the results of the classification errors rates and improvement over a random set of samples (20% of the original sample data) at different cut-off probability values. From Figure 17.1 it is possible to estimate that, for a cut-off value of 0.6, the model correctly predicts 98.51% of the cells for wolf-presence with just 24.17% of the cells wrongly classified with wolf-presence when in fact the species is absent (error type I). Subtracting these values, an improvement of 75.34% of cells correctly classified at 0.6 probability value was achieved (Figure 17.2). This is the optimal cut-off value at which the model performs with the most predictive success and lowest failure. Values over 0.6 therefore will be considered as indicative of a suitable habitat for wolves, and below that point an unsuitable one.

According to the model output, suitable areas are characterized by: low human perturbation levels (road density <0.1 km /sq. km, coverage of agricultural areas <10% and human density <5 inhabitants/sq. km); percentage cover by herbaceous and woody elements >40%; maximum temperatures below 14°C and elevation below 2 000 m.a.s.l.

The fact that the presence of roads on the landscape jeopardizes wildlife has been well documented for some species. In Wisconsin, Thiel (1995) found that road densities over 0.59 km/sq. km affected wolf breeding patterns. Fuller *et al.* (1992) reported similar results in some studies carried out in Minnesota. They reported a threshold of 0.70 km/sq. km for defining suitable habitat. Secure habitat is reduced for large mammals other than wolves, such as elks, wolverines, lynx and bears, when road densities are over 0.6 km/sq. km. Havlick *et al.* (1996) in a study carried out in the Northern Rockies found that a 0.48 km buffer distance is the minimum distance below which grizzly bears' use of the habitat decreases significantly. They suggested direct and indirect effects of road perturbation on habitats for wildlife. Among the direct effects are: forest fragmentation and increasing human activities, e.g. legal and illegal hunting, increased transport and industrial use of areas with a dense road network. On the other hand, the presence of roads, whether they are used or not, increases peak runoff levels and storm discharge due to local soil erosion.

17.4.3 Selection of areas for conservation or reintroduction

Figure 17.3a (see colour section) displays the model output of suitable areas with the current wolf distribution in the study area. Observed and predicted data for wolf presence and absence agree quite well in Canada and most of the USA. However, there are some regions in Canada, i.e. British Columbia and New Brunswick, and the conterminous United States, i.e. Utah, Colorado, Oregon, California and West Virginia, where wolves are absent and the model predicted them as suitable areas (see Figure 17.3a). Moreover, some zones with an unknown wolf occurrence were predicted as suitable areas, (these cells were not input as primary data for building the model), i.e. Labrador in Canada, the Northern Rockies and the Sierra Madre Occidental in Mexico. These regions have been highlighted in Figure 17.3b, showing their land-cover types. They are as follow: The Northern Rockies in Idaho, Wyoming, Montana (1) and British Columbia and Alberta (2); Labrador (3); New Brunswick and Nova Scotia (4); Minnesota, Michigan and Wisconsin (5); part of the Appalachian mountains in West Virginia (6); Utah, New Mexico and Colorado (7); Oregon and California (8) and the Sierra Madre Occidental in Chihuahua and Durango (9). These areas exhibit different wolf-habitat types (Figure 17.3b), and therefore the wolf should be protected or reintroduced in an example of each major vegetation type. At present there is a bias of wolf-management in protected areas (PA) on Tundra and Taiga vegetation types.

The US Fish and Wildlife Service (1980, 1987) has suggested that the optimum habitat for wolves would have to satisfy the requirements of: (1) A sufficient prey base; (2) suitable, secluded denning and rendezvous sites; (3) sufficient space with minimal exposure to humans; (4) maximum 10% of private land ownership; and (5) absence, if possible, of livestock grazing. Mech (1979) has estimated a minimum area of 10 000 sq. km to assure viable, well-functioning and well-organized wolf populations. He pointed out that if a smaller area is used, human/wolf interactions could be quite high around the edges. An area of 10 000 sq. km could support around 100 individuals (~10 breeding pairs for reintroduction). The Northern Rockies Recovery Plan followed these criteria and the proposed areas were located in North-western Montana, central Idaho and the Greater Yellowstone area (see zone 1 in Figure 17.3b) (USFWS, 1987). In 1995, 14 wolves were released in the Yellowstone National Park (YNP) and 15 in central Idaho. The following year 20 additional wolves were released in central Idaho and 17 in acclimatization pens in YNP (Fritts *et al.*, 1996). They pointed out that, by February 1996, at least 140 wolves were known to exist in the Northern Rockies: >70 in North-western Montana; 37 in the Yellowstone area (including 17 in pens awaiting release); and 33 in South-western Montana.

Combining criteria used by the USFWS for the recovery plan in the Northern Rockies and the minimum area suggested by Mech of 10 000 sq. km, it is possible to select areas for conservation where the wolf is still present or where it could be reintroduced. Considering that one ETM could be defined by the home range of one breeding pair and pups with a maximum number of 10 individuals per pack, the area suggested by Mech gives a conservative estimate of 10 ETMs as the minimum number of units to secure the top predator's population and species under its food chain.

Though zones located in optimal habitat for the Grey Wolf in Alaska comprise large extensions of federally-managed lands and wilderness areas currently under protection (greater than 10 000 sq. km), they include few different wolf habitat types (Figure 17.3b). On the contrary, some suitable areas located in Canada (zones 3 and 4), the conterminous United States (5, 6, 7 and 8) and in Mexico (9) comprise more variety of wolf-habitat types, i.e. deciduous broadleaf forests and woodlands, deciduous shrublands and drought deciduous woodlands, broadleaf shrublands and woodlands. Therefore, in order to secure the top predator's food chain, maintain high biodiversity and manage ecosystems efficiently, a wider range of wolf-habitat types should be considered for establishing new land use zones for wildlife management at the community level.

Finally, it has to be considered that the selection of areas for protection or reintroduction should take into account that wolves are a highly mobile species, which tends to follow prey migration. Recovery zones, therefore, or areas for protection should consider wolf dispersal corridors (Mech, 1996) and land use zoning (Clarson, 1996). These factors are quite important, since suitable areas, with nearly the minimum size to assure viable populations, are usually fragmented into smaller units and surrounded by zones with strong human activities and human presence. Therefore, considering public acceptance and sentiments, wolf corridors and land-use zoning based on existing or reintroduced wolf populations, e.g. setting boundaries for management zones with different levels of wolf control, public and private agricultural lands, will lead to an effective Wolf-management plan.

17.5 CONCLUSIONS

Establishing areas for protection is a controversial issue in wildlife conservation. Moreover, when protection involves predators, diverse and polarized opinions are raised among various public groups. Economic, political, biological, ethical and cultural values are involved in managing areas and protecting large carnivores. Hence, well-designed and well-conducted studies and the fullest support and understanding of people living in the area are needed when establishing land-use zones for wolf-management. Monitoring the whole wolf-geographical range in the Nearctic realm alone is an arduous and expensive task in terms of time and money. Therefore using the ETM with the aid of GIS and modelling could provide baseline studies to outline potential areas for predator-management and wildlife conservation. The outcome derived from this study should be seen as a method of proposing standards for conservation. Assessment of the application of these standards will require ground validation over a suitable timescale.

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Notes

1 'The Pyramid of Numbers' (Elton, 1927).

2 Pack territory size ranges from 40 to 664 sq. km but averaged between 100 to 250 sq. km (Fritts and Mech, 1981).

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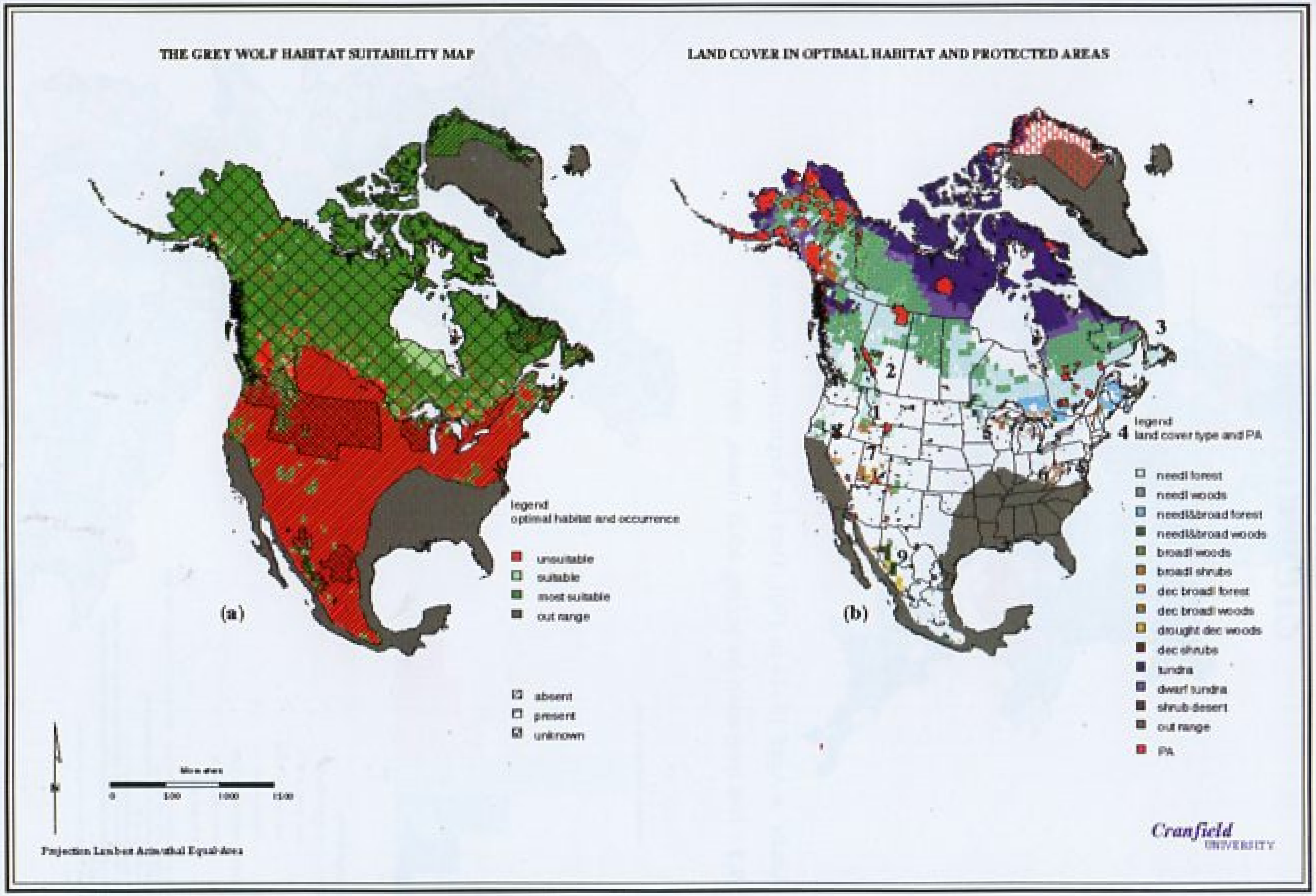

Figure 17.3 (a) The wolf-habitat suitability map with the species occurrence. (b) Land cover types in wolf-suitable habitat with Protected Areas outline (PA).