Use of satellite images for regional modelling of conservation areas for wolves in the Carpathian Mountains, central Europe.

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Abstract ˆ – This study analysed the spatial structure of the Carpathian Mountains, in Central Europe, considering it a unit that extends across national boundaries, and assessing the suitability of areas were wolves could be conserved. Physical characteristics of the area were extracted from NOAA-AVHRR NDVI. A set of 9 images from different periods of the year was used to parameterise the phenological variability of the area. Digital maps of road networks, human settlements and a DEM were integrated in a GIS. Locations of wolf presence were used to extract "optimal" environmental characteristics that served as reference for estimating the degree of suitability over the whole area. Results show that most of the Carpathian Mountains are highly suitable for the wolf and that highly suitable areas are actually inhabited by the present population of wolf. These are also the area most phenologically stable.

INTRODUCTION

The geographic distribution of species is a challenging issue in conservation biology and the identification of areas that are critical for species is the first step towards any conservation actions. The selection of species that are at high trophic levels is one way of optimising conservation efforts as the survival of such species imply the protection of many other species (i.e., the prey) and extensive habitats. This is the case for large carnivores, species that generally roam over large areas, are sensitive to human disturbance, and feed over a number of wild animals that thus need to be protected (Gittleman *et al*., 2001). In Europe, there are few species of large carnivores, as the impact of human actions has been fatal for many species throughout the centuries. Among them, the wolf (*Canis lupus*) is particularly interesting for conservationists, as its relationship with humans has always been marred by conflict.

Wolves were once distributed over most of continental Europe. They underwent processes of local extinction and now present highly fragmented distributions (Boitani, 2000). Within the Central-Eastern part of Europe, the populations of wolves in the Carpathian Mountains are remarkable as they spread across the mountain range at high densities, suggesting the need for large-area, trans-national management that would consider the populations as units.

In this study we aim at identifying areas associated with different degrees of 'goodness' for the wolf in the Carpathian Mountains. We used a continuous probabilistic approach in a geographical information system (GIS) in order to produce maps representing the Carpathians as a unit within which areas suitable for the conservation of wolf may be identified. We used normalized digital vegetation index (NDVI) for characterising the environment, bypassing the image classification process, thus simplifying the use of multi-temporal satellite images and avoiding the errors associated with land cover classifications.

STUDY AREA AND METHODS

The Carpathian Mountains

The Carpathians are the second largest chain of mountains in Central Europe after the Alps. They spread from the Danube River area of Slovakia, to the Iron Gate on the Romanian Danube at their south-eastern end (Fig. 1), covering an area of approximately 160,000 km^2.

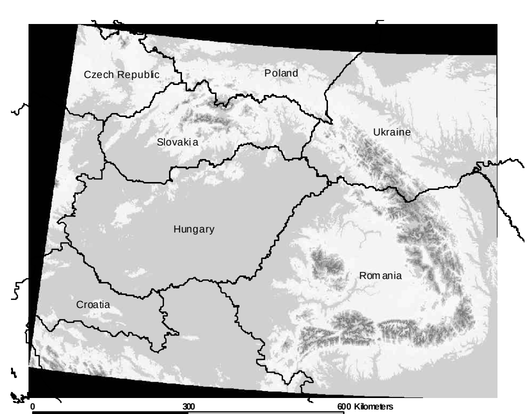

Fig. 1. Location of the Carpathian Mountains in Central Europe.

This work is part of a project funded by WWF International and coordinated by the WWF International Large Carnivore Initiative for Europe, aimed at modelling conservation areas for bear, lynx and wolf in the Carpathians.

The mountain complex is divided between 7 countries: Austria, the Czech Republic, Slovakia, Poland, Hungary, Ukraine and Romania. In this paper we focus only on countries that contain at least 10% of the Carpathians within their territory, considering that smaller areas at the boundary of the mountains are not vital for the conservation of the Carpathian wolf population. Our discussion is thus limited to Poland, Slovakia, Ukraine and Romania, which all together contain 90% of the Carpathian chain (Table 1).

Table 1. Wolf population estimates, conservation status, and Carpathians portions in the four countries considered. SP = Strictly Protected; P = Protected; PP = Partially Protected; NP = Not Protected.

	POP. ESTIMATE	CONS. STATUS	CARP. PORTION (%)	AREA (km^2)
Slovakia	300	PP	17	35,4
Poland	250	SP	9	18,9
Ukraine	400	NP	10	21,6
Romania	3,000	P	52	107,2

Wolves in the Carpathians

The Carpathian wolf population is the largest in Europe, despite the fact that the Carpathians cover an area not larger than 1% of Europe. The Carpathian wolves represent around 30% of European population (data from Boitani, 2000). The estimated population sizes for the wolf in the Carpathian countries is reported in Table 1, together with the proportion of the Carpathians contained in each of the four countries considered. All four countries have signed the Bern Convention, which stimulates the conservation of European carnivores, but effective legislation for the protection of wolf has been adapted to local situations (Okarma 1993). The species is strictly protected only in some countries, where compensation for the damage they cause is offered by conservation agencies, whereas in others (e.g., Ukraine) it is still considered a pest and bounties are paid for its removal.

Modelling approach

The methodology used follows a procedure successfully developed and applied by Corsi *et al.* (1999) and IEA (1998) for modelling areas for conservation of large carnivores on the Alps. The analytical approach uses multivariate statistical methods to spatially identify areas that are associated with various degrees of environmental suitability. Such suitability classes are established according to the environmental characteristics of areas where the presence of wolf was recorded. The approach extracts the environmental characteristics of the locations where wolves have been recorded. Averaging the values of environmental variables found at each location provide an estimate of the 'ecological signature' of the wolf. Comparisons between the ecological signature and the ecological characteristics of any other location within the study area allow the establishment of a suitability degree based on the difference between them. Thus, the greater the difference between any given location *A* and the ecological signature, the lower the suitability degree assigned to *A*.

Variables used

The environmental variables considered (Table 2) were selected on the basis of expert knowledge and availability. Wolves in the Carpathians seem to occupy most of the forested areas, where human impact is least, although some isolated cases of wolf sightings in urban areas have been reported (A. Mertens, pers. comm.). As most carnivore species, the presence of wolf in the Carpathians is expected to depend on availability of food, cover and the absence of human disturbance.
The density of wild prey species was not available for the countries considered. Cover was estimated using the NDVI of NOAA-AVHRR images of the Carpathians.

The NDVI provides a measure of the relative amount of actively-photosynthesizing vegetation within an area (Hay *et al*, 1998). In order to phenologically characterise the region, thus accounting for the seasonal variation in the amount of live vegetation, we used a total of 9 NDVI images from different months of the year, from March to October 1995. The images came from the 10-day composite dataset available from the USGS and cloud cover was always minimal. Human presence was accounted for by considering the road and railway networks and a map of human settlements within the study area.

Table 2. Variables used and spatial resolutions at which they were originally acquired for each country considered.

	RO	SK	PL	UA
NDVI	1.1 km	1.1 km	1.1 km	1.1 km
SETTLES	1:200,000	1:50,000	1:50,000	1:200,000
RAILWAYS	1:200,000	1:50,000	1:50,000	1:200,000
ROADS	1:200,000	1:50,000	1:100,000	1:200,000
ELEVATION	1.1km	1.1km	1.1km	1.1km
WOLF LOC	1:200,000	1:200,000	1:250,000	1:1,000,000

A digital elevation model (produced by the USGS at 1 km spatial resolution) of the area was also used to account for the terrain structure of the mountain complex. Finally, the wolf locations were obtained by local researchers, foresters and hunters and were transformed in to a layer of point locations. Territories were not available.

Data Analysis

Variables were obtained in digital format. All but those provided by the USGS were acquired for each country separately. The spatial scales and geographic projections were inconsistent, thus a pre-processing phase included data transforming and editing for correcting the discrepancies between the four countries. Vector layers were then rasterised using the USGS products as reference grid.

In order to consider the perception of space of the wolf, we averaged pixel values of each variables using a circular window of 5 pixels radius, thus obtaining the most similar size of an average wolf territory (i.e., 82 km^2, as estimated by Okarma, 1991; and Find'o, in prep., for the Polish and Slovak Carpathians, respectively). The smoothed topology themes coming from vector layers were then converted in values of % cover by dividing each pixel for the area of the smoothing window and multiplying them by 100.

The wolf ecological signature was defined as the vector of the means of the values of each environmental variable in the wolf locations (n=224) together with its the dispersion matrix.

We used the Mahalanobis distance measure for characterising each pixel of the study area in terms of multivariate distance from the wolf ecological signature. The Mahalanobis distance is a multivariate technique, therefore it is most appropriate for environmental modelling, and it has the great advantage of accounting for correlated variables through the variance-covariance matrix. The squared distance is calculated as

$$D^2(x) = (x-m)\, S^{-1}\, (x-m)' \qquad (1)$$

where x is any given location in the study area, m is the wolf ecological signature, and the S^{-1} is the inverse variance-covariance matrix.

The output values were divided into classes by a slicing process based on the values of D^2 corresponding to the pixels at wolf locations. The mean and SD of such values were used such that:

Class 1 = 0 up to the mean	Class 2 = mean + 1SD
Class 3 = mean + 2SD	Class 4 = mean + 3SD
Class 5 = mean + 4SD	Class 6 = mean + 5SD
Class 7 = mean + > 5SD	

Given that the values are always > 0 and that the lowest is the most similar to the ecological signature, this system provides an objective way to increasingly include values that depart from the ecological signature.
The resulting raster image was then compared with a map of the wolf distribution in the Carpathians provided as a sketch by local experts.

The raster images of the NDVI were pooled together to produce an index of phenological variability through the coefficient of variation (CV), calculated as the ratio between the SD and the mean values for each pixel. The output raster image was then used to estimate how much of each suitability class actually included phenologically variable areas.

RESULTS

Most of the Carpathians fell into the first suitability class, and when the first two suitability classes were pooled together, over 75% of the area was included. Fig. 2 shows the graphical representation of the output.

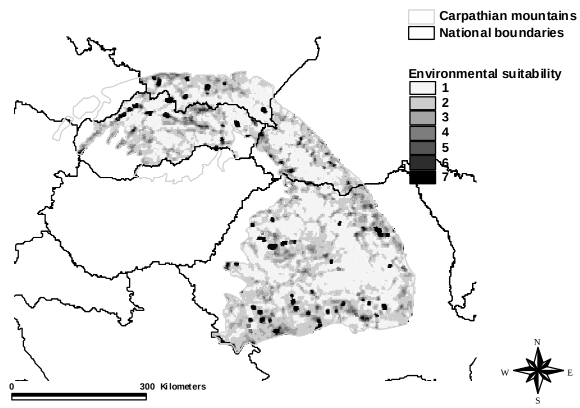

Fig. 2. Graphic representation of the outputs from the Mahalanobis distance statistics for environmental suitability for the wolf.

The percentages of the Carpathian Mountains included in each class are shown in fig. 3. The spatial distribution of high degree of suitability is mostly continuous and 71% of the total area in class 1 is made up of patches that are at least as large as two wolf territories. Such percentage goes up to 78.7% when pooling class 1 and 2, and it is all included in one large and continuous area.

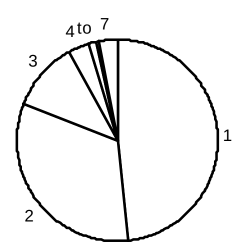

Fig. 3. Percentages of Carpathian territory included in the suitability classes produced with the Mahalanobis distance.

Values of phenological variability ranged from 0 to 153 (mean = 0.11, SD = 2.21), but as 95% of the data were included in values < 5, 8 classes where defined using 10 as maximum value. Up to 60% of the Carpathians show low variability (CV <= 0.08) and the percentages of variability classes included in the first two suitability classes are reported in fig. 4.

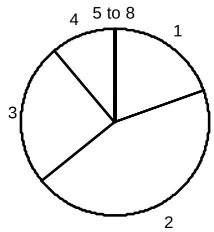

Fig. 4. Percentages of variability classes in the suitability classes 1 and 2 for wolf in the Carpathians.

The main portion of highly suitable areas is composed of areas that are associated with low phenological variability. The comparison between the different environment suitability classes and the distribution of wolf as sketched by local experts showed that 48% of the wolf range was included in the suitability class 1, and 32% in suitability class 2.

DISCUSSION

The consideration of the Carpathian Mountains as a unit is of paramount importance within the management of wolves at a pan-European scale. The mountain range represents one of the areas within Europe where the carnivore is present at extraordinary high density. The Carpathian wolf population spreads continuously across the region and any management approach should tend to be consistent across the different Carpathian countries. Once the 'big picture' is achieved, it should serve for identifying areas where detailed studies may be carried out, and where protection priority areas may be established.

The spatial resolution of 1 km is suitable at such a scale of analysis, particularly for a species that roam across large areas (Riitters *et al.*, 1997). Nevertheless, it must be underlined that the analytical approach adopted in this study produces outputs that are specific for the target species and area. The resulting values should not be taken as absolute values of suitability, but rather as relative within the area (Corsi *et al*., 1999). The outputs produced should be considered the starting point for more detailed analyses and its main strength is the optimisation of limited information available. The advantage of using NDVI versus land cover maps is that not only the NDVI allows the characterisation of the dynamic of vegetated areas, but also it is straight forward to use and does not require lengthy image processing phases as image classification does. Being it a ratio-based index, it provides some compensation for the effects of variable illumination due to topography.

The high proportion of the Carpathians included in the high suitability classes suggests that the extensive forests and the relatively low human population density make the mountain range of conservation priority, aiming at a pro-active approach.

The Carpathians are one of the few areas in Europe where wolves are presently enjoying a continuous distribution, but where the threat of habitat loss and fragmentation is imminent due to fast economic growth. The characterisation of the Carpathians in terms of phenological variability highlights the importance of forested areas that are photosynthetically active for most of the year. These are the areas under major threat due to their economic value. In view of the potential threat for habitat fragmentation, the output of the present study could be used for identifying possible corridors in future management plans, taking into account that protected areas are seldom large enough for supporting viable wolf populations (Noss *et al*., 1996). The inclusion of other variables, such as prey density and human attitudes would certainly represent a highly valuable input in the model (Clark *et al*., 1996) and future work should be aimed at gathering detailed information to be used in an integrated management approach.

Finally, we recognise that validation of results is an essential phase in GIS modelling and future work will include collection of presence data in the field in order to validate outputs obtained.

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