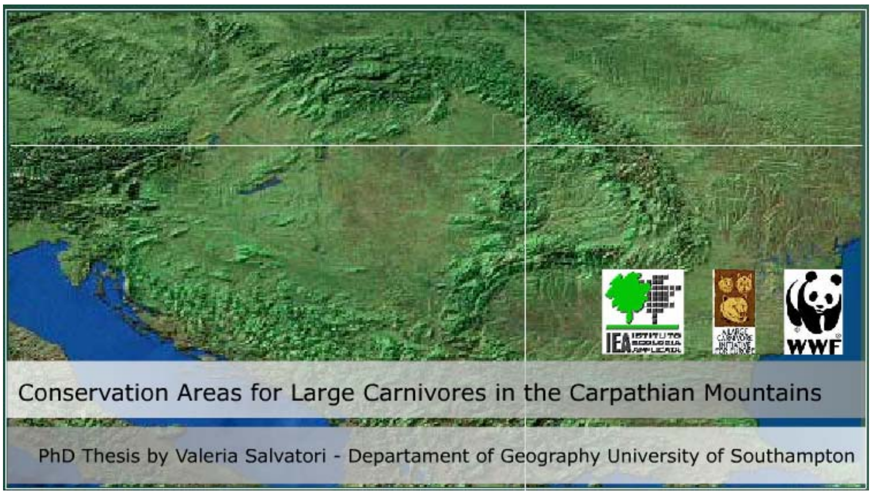
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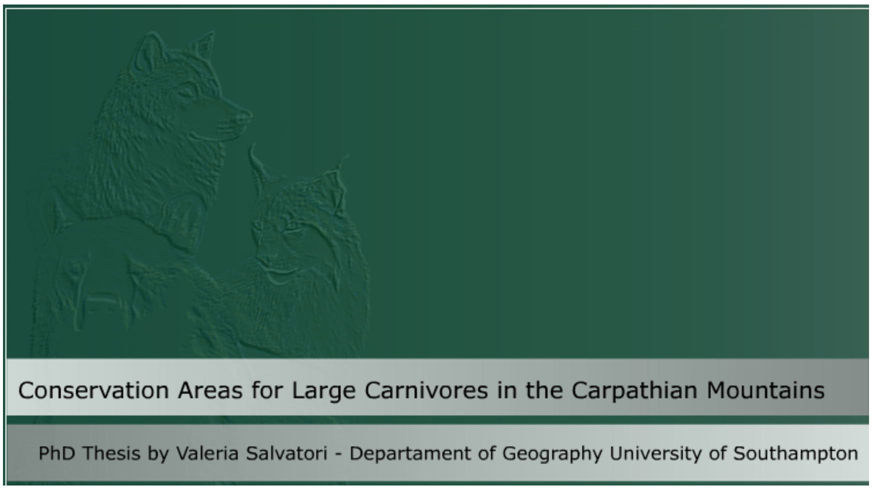
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UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING, SCIENCES & MATHEMATICS

School of Geography

MAPPING CONSERVATION AREAS FOR CARNIVORES IN THE CARPATHIAN MOUNTAINS

by

Valeria Salvatori, B.Sc., M.Sc.

Thesis for the degree of Doctor of Philosophy

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UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

SCHOOL OF GEOGRAPHY

Doctor of Philosophy

MAPPING CONSERVATION AREAS FOR CARNIVORES IN THE CARPATHIAN MOUNTAINS

By Valeria Salvatori

The present study is an effort towards the international and multidisciplinary approach to conservation of European biodiversity. The main aim was to map the distribution of suitable areas for the conservation of bears, lynx and wolves in the Carpathian Mountains. It was done applying a distance classifier, the Mahalanobis distance, over a set of environmental variables representing the region.

The results suggested that 41, 58 and 65% of the Carpathian Ecoregion is highly suitable for bear, lynx and wolf, respectively. Considering the three carnivores at once, 20% of the area is highly suitable.

Suitable areas are fragmented, but interspersed with areas of less suitability value, without being isolated, and spatially distributed all along the Mountain range.

The results were validated with an independent data set and results suggest that the model produced an acceptable estimate of the areas effectively occupied by the carnivores. The comparison between suitability maps obtained with the two independent data sets showed that they were consistent, always reaching values of K-Statistics > 0.5.

A comparison was made using input data at three spatial resolutions (1km, 250m and 30m). The results obtained were highly dependent on the details provided by the baseline data, although the general trends were consistent. This may depend on the type of input data and the portion of subjective input in the land cover classification data. The latter aspect was further explored through the testing of whether the use of unclassified satellite images, in the form of vegetation index, could replace the land cover maps. It appeared that such a replacement may be conditional to the area considered and the amount of human activities, as well as the ecological needs of the species. In the present study, the results obtained with unclassified images were poorer than those obtained with land cover maps.

The development of human activities over the land poses problems of how to integrate land exploitation and biodiversity conservation. The outputs of the environmental modelling exercise were used for estimating the distribution of potential conflicts between the presence of carnivores and livestock husbandry practices. Results suggested an effective management would avoid the summer grazing of livestock in carnivore areas and the use of damage prevention measures. The actual effect of currently protected areas in the region was assessed and the need of an increased portion of protected land, particularly in Romania and Ukraine emerged after analysing the proportion of highly suitable areas for large carnivores under any kind of legal protection.

DECLARATION OF AUTHORSHIP

I, *Valeria Salvatori*, declare that the thesis entitled '*Mapping Conservation Areas for Carnivores in the Carpathian Mountains*' and the work presented in it are my own. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly
- what was done by others and what I have contributed myself;
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Signed: …… …………………………………………..

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1. INTRODUCTION: THE CONTRIBUTION OF CARNIVORES TO THE CONSERVATION OF BIODIVERSITY

1.1 Introduction

The present project aims at identifying areas that are suitable for the conservation of bears, lynx and wolves in the Carpathian Mountains. It was funded by WWF International and represents an example of pro-active conservation in a region covered by some EU accession countries.

The Carpathian Mountains are shared by seven different countries in Central Europe and they host an impressive extent of natural temperate forests. Their geographical location and the environmental conditions have allowed the development of a high degree of biodiversity. Particularly, the presence of key species makes the area of paramount importance when considered at pan-European scale. The populations of such species need to be conserved throughout the process of EU accession and economic development, thus it is important to identify key areas to be preserved from human disturbance.

The approach adopted here was to assume that large carnivores as bears, lynx and wolves are could be proxies for the conservation of biodiversity in the Carpathian Mountains. These species stimulate controversial feelings. Thus, in the different stages of the present work, it was needed to tackle technical as well as social issues.

In order to introduce the reader to the complex world of biodiversity conservation, an overview of the main concepts and the role that carnivores may play in it is given in chapter 1. One of the aspects that emerges as fundamental for any action to be put in place is certainly the spatial distribution of targets, their location in space and their position relative to other relevant features. All these concepts will be the subject of chapter 2, where a description on how to focus on the spatial dimension of biodiversity, and particularly wildlife conservation will be given. This will help the reader to understand the different technical tools available and their applications. Upon this background, a series of punctual objectives were set, and they are listed at the end of the chapter. The three species targeted – bear, lynx and wolf – will be briefly introduced in chapter 3, together with the description of the region considered. The information given will be necessary to understand (a) some of the technical artefacts needed for representing the species-specific needs, and (b) the complexity of dealing with a multinational issue. Chapter 4 represents the technical report of data collection and pre-processing, which needed to go through a challenging phase of social equilibria, negotiations, agreements and resource management. The results showing the suitable areas for conservation of bears, lynx and wolves in the Carpathians are reported in chapter 5, which also includes their validation.

The chapters 6 and 7 build upon the results achieved and test the adequacy of using data at different spatial resolutions (ch. 6) and the potentials for using environmental data of different nature (ch. 7). Finally, chapter 8 will put the results obtained into the real context, considering the potential efficacy of existing protected areas for the conservation of the three carnivores and the conflicts their presence cause with human activities, thus showing the utility of the study for management purposes.

The present chapter represents an introduction to some of the basics that need to be considered in order to understand why carnivores are good for the conservation of biodiversity and how this may be done, issues that will be investigated throughout the course of the thesis.

1.2 What is Biological Diversity?

Biodiversity is a term with a broad meaning that can be seen at many levels. In his book *The Diversity of Life* (1992), Edward O. Wilson defines biodiversity as "The variety of organisms considered at all levels, from genetic variants belonging to the same species to arrays of genera, families, and still higher taxonomic levels; including the variety of ecosystems, which comprise both communities of organisms within particular habitats and the physical conditions under which they live". The definition could be even broader, including biomes, species interactions, and ecosystem processes (Spellerberg 1996). The World Wide Fund for Nature (1989) defines biodiversity as "the millions of plants, animals and micro-organisms, the genes they contain, and the intricate ecosystems they help build into the living environment". All these definitions suggest that biodiversity can be identified at least at three levels: (i) genetics, (ii) species and (iii) community.

1.2.1 Genetic diversity

The variety of genetic material within a species is of vital importance and is the basis of evolutionary processes. The two main sources of genetic variation are mutations and sexual reproduction. Mutations can develop naturally by chance, or be induced by external factors (e.g., radioactivity).

Individuals belonging to the same species are usually geographically separated into groups called populations. Within a population, individuals differ in their genetic makeup, which is mixed at every sexual reproduction event.

The gene pool of a population is represented by all the different forms in which a gene expresses itself in every individual belonging to the same population. When a population is isolated for a number of generations, the genetic pool tends to lose part of its variability, allowing the expression of weak or rare genes. In certain cases the isolation can be so effective that a new species may arise, but more commonly the individuals of the isolated population become infection-prone or lack resilience for surviving environmental changes, showing an increase in infant mortality because deleterious traits are inherited in the progeny (Caughley and Gunn 1996). In such situation the term *inbreeding depression* may be used to describe the depletion of genetic variation (Gilpin and Soulé 1986). In order to maintain levels of genetic diversity that ensure the population remains healthy and viable, reproduction should take place between individuals coming from different populations, producing a gene flow among populations. The process of habitat loss and fragmentation produced by human activities has a strong potential in preventing the gene flow among populations. The spatial structure of the environment determines the potential for movement of individuals among populations, thus contributing to the diversity of the genetic set of the species. This is the reason why habitat connectivity and biocorridors are extremely important.

This aspect will be investigated in this study, where a spatial analysis of habitat fragmentation will be undertaken, thus discussing the potentials of bears, lynx and wolves to move among patches of suitable areas.

1.2.2 Species diversity

The number of different species in an area may be called species diversity. Considering the spatial extent of species, the population can be considered the species' unit, so that although different populations may show morphological differences, they belong to the same species if they are potentially able to interbreed. The diversity of species is usually measured at geographically limited units as the number of species present within a given area (Hengeveld *et al*. 1995).

It is important to note that the presence of one species inevitably depends on the presence of other species, creating a complex web of interactions sometimes very difficult to identify. The consideration of several species at once is challenging in this respect, and it is becoming the prominent view of conservation biology of the last 10 years (Meffe and Carroll 1997). This study will focus on the European population of large carnivores, particularly dealing with the subpopulation present in the Carpathian Mountains. The degree of isolation of the Carpathian Mountains from the other European areas where the carnivores are present will not be assessed here, because this falls out of the scope of the project. An attempt at using the synergies that may be present when multiple species, with their different associated needs, have to be conserved in the same area will be made.

1.2.3 Community diversity

Scaling up across spatial resolution, the species interact among each other in order to form communities. A biological community is the set of species - and the relationships among them - that occupy a given area (Putman 1994). The association of a community and the physical environment it develops in is called an ecosystem. The characteristics of the physical environment, its climate, its soil properties, location and aspect determine the type of community that may develop. The community, in turn, can alter some of the physical characteristics by, for example, acidifying the soil or retaining humidity. This suggests that very rarely two ecosystems in different geographical places can be identical, although regulated by similar relationships and parameters. This makes the Carpathian population of carnivores a unique community within Europe, although the same species do live in other areas, such the Alps, the Scandinavian Peninsula, and the Balkans.

In theory, each species occupies a physical and biological space, contributing in its unique way to the structure of the biological community of which it is a part. In practice, there is an array of spaces that are used by a species, depending on the environmental conditions. This space is called the *ecological niche*, and the variability attached to it is termed the niche breadth (Morrison *et al.* 1998). A species with a broad ecological niche is also said to have a broad ecological valence.

The interactions among species and the roles they play in the ecosystems are organised into trophic levels between which energy is transferred (Putman 1994). The trophic levels are part of the food chain that exists in all ecosystems and which constitutes the transformation of energy into different forms. In a trophic chain primary production, which is the lowest level of production, is usually represented by plants that transform sunlight firstly into chemical energy and then into organic matter via the process of photosynthesis. Successively higher levels are represented firstly by animals that feed on plants, and subsequently by animals that prey on other animals. At a theoretical equilibrium, predators control the prey population by keeping it at levels that the ecosystem can sustain. Large carnivores are at the top of the trophic chain, and they depend on a series of other species.

The presence of carnivores thus can be thought as an index for the presence of their prey species. For this reason they are called *umbrella species*. They are species with broad requirements that include those of a number of other species (Simberloff 1998). Identifying umbrella species would allow conservationists to stay on the safe side: they may act towards the conservation of ecosystems through the conservation of species that require large areas of relatively natural or unaltered habitat for the maintenance of viable population (Meffe and Carroll 1997). Their conservation will indirectly secure the conservation of the others. This study focuses on three large carnivores that can be considered umbrella species as they occupy large areas that may include ranges and habitats suitable for other species.

Finally, as an answer to the question set as title of this section, biodiversity can be thought of as the potentiality for an ecosystem to return to its previous natural equilibrium; or as the ability to find a new point of equilibrium after being disturbed by external causes (most commonly human activity). Thus, measuring biodiversity changes through time is a measure of the resilience of an ecosystem. In an anthropocentric view, it could be considered as a measure of its potential to continue the production of primary goods (Perrings 1995). Conservation of the original level of biodiversity leads, therefore, to the preservation of variety and interactions between species, and processes in ecosystems. It can be considered an investment either through a refrain on current consumption of land or species by humans, or the allocation of space and management techniques to enhance the survival of species (Bulte and van Kooten 2000). The present project represents a contribution to the conservation of European biodiversity in that it offers a baseline picture of the Carpathian biodiversity that is threatened by the economic changes the Carpathian countries will face through the process of joining the EEC.

1.3 Ways of conserving biodiversity

The discipline of Conservation Biology has developed in response to the crisis of biodiversity loss and has two main objectives: (i) to investigate human impact on species, communities and ecosystems; and (ii) to develop new strategies and techniques to prevent the extinction of species and eventually reintegrate those in danger of extinction into their properly-functioning natural habitat (Primack 1998). The interest of humans for wild species and ecosystems has ancient roots, and the innovative approaches to conservation that characterise Conservation Biology, and include the economic and opportunistic values of biodiversity can be considered as different means to obtain the same result: lower the rate of species extinction.

One of the causes of species extinction is their over-consumption by humans. Prehistoric people were mainly hunters and their population density never reached densities that would threaten their prey, although some theories have been advanced making them responsible for local extinctions. The cultural and behavioural changes in human society, especially the shift to agricultural practices and husbandry, have made the hunting of wild species less important for human sustenance. Some cultures attribute special properties (usually medicinal) to specific parts of animal bodies and hunt them to only extract that part, or hunt wild species for trading their furs (Johnson *et al.* 2001). Hunting is nowadays a cultural activity in Western society and its regulation and the management of game populations has become necessary in order to prevent species extinction (Cox and Moore 1993). This is very real in the Eastern European countries, where hunting is practiced by most of the population in rural areas. In some areas of the Carpathians, the hunting tourism industry has developed well, and western hunters pay significant amount of money for a hunting trip to Poland or Romania. Species to be hunted include bears and wolf as well as big herbivores and birds. This calls for an active management of hunting activities, linked with International legislation that also require the designation of areas where hunting may be practiced as well as quotas of animals to be cropped.

Conservation biology is currently focused much more on preserving the processes that generate wilderness *in situ*, and accepting whatever states of biodiversity result from those processes. In this sense, conservation biology must be a multidisciplinary subject that aims at conserving the environment while considering the human population as part of it, as well as trying to reach compromises between interests coming from different parties (Blockstein 1999). It has an intrinsic dynamic that includes scientific, socio-economic, educational, engineering and legislative aspects and that should aim at managing dynamic ecosystems that maintain natural processes (Grumbine 1994, Samson and Knopf 1993). Such aspects will be considered in this study, where biophysical characteristics of the environment will be considered together with legislation and anthropogenic activities in the development of guidelines for the conservation of carnivores in Central Europe.

Conservation biologists are *crisis managers* who consider each single organism as a masterpiece worth the effort and care needed to avoid its extinction (Wilson 2000). They can plan ahead and act to avoid the loss of biodiversity, if the degree of understanding of natural ecosystems is enough for them to be satisfactorily pro-active. The tools available to conservation biologists are diverse and are sometimes borrowed from different disciplines. Nevertheless, their integration can sometimes be challenging and the present study represents an effort in this direction.

In order to conserve biodiversity, basic knowledge of the natural history of target species is of vital importance (Curio 1996). Although national and international environmental policies are setting standards in order to conserve the world's diversity at global and local scales (McLean *et al*. 1999), the standards and targets set are of debatable help for conservation if they do not take into consideration the relative distribution of biodiversity (Soulé and Sanjayan 1998) among countries and around the world. For this reason, areas of particularly high level of biodiversity are mapped globally (Myers *et al.* 2000). It is evident how a scientifically-based guide for the investment of resources in the conservation of biodiversity is needed. In the present study, it was assumed that large carnivores would represent proxies of high biodiversity areas for some characteristics that will be illustrated in the following section.

1.4 The conservation of Large Carnivores: challenges and frustrations

The conservation of species at the highest trophic level is an attempt to conserve the processes that are required to maintain all the lower levels needed to sustain the whole chain. Maintaining viable populations of predators may target the objective, but it can be particularly difficult as they are sometimes in bitter conflict with human activities (Ginsberg 2001). Included in such a group are the large mammals belonging to the *Carnivora* family such as tiger (*Panthera tigris*), puma (*Felis concolor*), leopard (*Panthera pardus*), lynx (*Lynx lynx*), wolf (*Canis lupus*), coyote (*Canis latrans*), bears (*Ursus spp.*) and hyenas (*Crocuta crocuta*, *Hyena spp.*) among others.

Large carnivores have attracted human attention ever since human evolution started. In the culture of some Native American tribes, the wolf and the bear were considered part of nature and positive source of inspiration (Lopez 1978). The perception of western societies towards large carnivores has historically been negative, being considered as competitors for hunting species or livestock predators (Fuller 1995, Sillero-Zubiri and Laurenson 2001). The cultural knowledge of these species has been influenced by traditional stories and beliefs that pictured them as bad and generally dangerous for humans. In Europe, such view was strengthened by the Judeo-Christian belief that human beings are superior creatures empowered to dominate nature in a utilitarian fashion (White 1973). Only in the last decades has this attitude been reviewed and in some cases reverted, as indicated by the high number of wildlife protection agencies and lobbies that are now strongly active in the process of conservation (Gittleman *et al.* 2001).

Large mammalian carnivores are undoubtedly a challenging group of organisms for conservation biologists. Their ecological characteristics make them at the same time attractive and frightful for the public, they are big and fierce, rare, elusive and dangerous (Gittleman *et al.* 2001). Their role in wildlife causes them to be admired for their power, freedom, beauty, and intriguing and vulnerable nature (Fuller 1995).

Large carnivores require extensive areas of land for maintaining healthy population structures (Woodroffe 2001). Some of them are solitary animals, hunting on their own and joining individuals of their same species only during the reproduction period, while others have a social behaviour, living in groups of several individuals. Depending on their social organisation, the area required by a single individual to cover its natural needs (the *home range*) may vary from few to hundreds of square km. Although they often avoid human-dominated areas, large carnivores do not necessarily prefer wilderness areas, rather they find it easier to survive far away from human persecution and disturbance (Shaffer 1992, Ciucci and Boitani 1998).

The populations of large carnivores around the world have been declining and most of them are listed as in danger of extinction by the International Union for the Conservation of Nature and Natural Resources (IUCN

1990, Purvis *et al.* 2001).

The problem of conserving large carnivores is complex and multi-faceted, and, as Ginsberg (2001) suggests, carnivore conservation is different from biodiversity conservation. This is attributable to the fact that carnivores in general occupy a particular place in the human's imaginary, culture and feelings (Macdonald 2001). Some of the forces that caused large carnivores to decline are identifiable in direct and indirect killing and habitat destruction, both attributable to human action. These activities are still operating today, although at lower rates than they were in the last century. The problem, though, would be oversimplified if were to be reduced to a cause-and-effect phenomenon induced by human action. The problem is a myriad of site-specific human and ecological forces (Clark *et al*. 1996). Clark *et al.* (2001) underline the multidisciplinary character of carnivore conservation and note that it rests on science and culture, thus highlighting the importance of human knowledge and perception of large carnivores.

The approach to carnivore conservation has hitherto focused on single species and local populations (Ginsberg 2001). Most importantly, conservation programmes have been based exclusively on scientific knowledge and biological needs. This is probably the main reason why many of them have failed to conserve viable populations of large carnivores (Clark *et al.* 1996, 2001). There is an array of factors not based upon any ecological or scientific knowledge that have a strong influence on the outcome of conservation programmes, and these are of socio-economic, political, historical and cultural nature (Clark *et al.* 1996, Bath 1998, Bekoff 2001). There is little possibility that a conservation programme with a strong scientific basis and excellent technical staff and equipment would have a positive outcome if the local population was against it, as illegal killing and poaching would be major causes of mortality that are impossible to eradicate from the system (Clark *et al.* 2001).

Because many carnivores occupy areas where human activities are present, the conflict of interests on the land is often very strong (Sillero-Zubiri and Laurenson 2001). Antagonistic attitudes toward large carnivores are based on historical and cultural fears, concerns for human safety, beliefs about real or perceived competition with humans for livestock, game and habitat, fear for losing property rights over the land, and negative symbolism such as ferociousness or viciousness (Kellert *et al.* 1996). Bath and Buchanan (1989) found that human attitudes towards large carnivores changed from negative to positive with distance from the areas where the carnivores were. There is, therefore, a spatial dimension in the human attitude toward large carnivores, whereby people who are in direct contact with the consequences of carnivore presence are sometimes unable to adapt to it. The involvement of the public into wildlife management has become a basic requirement for developing successful programmes. Public involvement can take many forms and is essentially about redistributing power from the technicians to the public (Bath 1998, Sillero-Zubiri and Laurenson 2001). The way this is done is very much dependent on the cultural level, and the interests and the willingness of the public to be involved in the process.

The general idea that conserving wildlife is in contrast with economic development is strongly rooted in western societies, whose resource-based economy regards top predators as vermin (Rasker and Hackman 1996). Because large carnivores require large areas of wilderness, their conservation is often seen as a luxury whose cost in forgone jobs and resources cannot be justified. Nevertheless, there are some cases where the conservation of carnivores has not been an obstacle to employment and economic development. Rasker and Hackman (1996) report cases where in regions with large wilderness areas protected from human development, the income and employment growth were higher than in resource extractive regions. The authors suggest that a relationship between carnivore conservation and economic growth could not be drawn, but evidence that environmental protection necessarily harms economic performance was not found (Rasker and Hackman 1996). Tourism and its associated industries represent economic opportunities that could be enhanced by environmental protection. Some populations of carnivores could even be managed in such a way that their exploitation could represent a revenue for local communities (Sillero-Zubiri and Laurenson 2001). This is the case with bears in Romania, where they can be hunted under strict regulations, and foreign hunters are requested to pay high fees for a hunting trip (Salvatori *et al.* 2002, see chap. 8).

The effort towards carnivore conservation needs to be of such magnitude that contributions from different sources (both economic, intellectual, scientific and politic) ought to be sought for. But the very first step towards conservation of carnivores is the identification of areas where action should be focused in order to make a conservation strategy operational (Ginsberg 2001). The Ecoregional approach (Olson and Dinerstein 1997) most likely reproduce the limits posed to a population of large carnivores (Ginsberg 2001). For this reason, in the present study, the ecoregional approach to environmental analyses was adopted in an attempt to identify the areas that would be most suitable for the conservation of three European large carnivore species.

1.5 Conclusions

The conservation of biodiversity requires a multidisciplinary approach calling for international collaboration and socio-economic inputs as well as technical and scientific studies. Identifying species that significantly contribute to achieving the aim of decreasing the rate of biodiversity loss is of vital importance. Such species need to be particularly representative of the biodiversity of a certain area, and large carnivores can certainly be adequate proxies of the Carpathian biodiversity, given their role of umbrella species, thus covering the ecological requirements of a number of other species at an inferior trophic level.

The conservation of species that bring conflicts with human activities and that roam across large areas is particularly challenging and requires the integration of science and tools that allow the consideration of social, physical and biological aspects of the environment. In this respect, a broad-scale approach is becoming essential, where pro-active management and social involvement are integrated with science.

Elaborating a strategy, though, is not enough if the area where it is to be applied has not been identified. The spatial dimension of biodiversity conservation represents a starting point upon which multi-disciplinary actions should be applied. As a support to this, the analysis of large areas has become easier with the aid of new analytical and data capturing/management tools such as geographical information systems and remote sensors. The geographical attributes of wildlife conservation will be the focus of the next chapter, where a review of the approaches and techniques used insofar will be given. The present study has a strong spatial attribute, as the main objective set is to map the environmental suitability for large carnivores in the Carpathian Mountains. The method adopted for achieving this objective will be described in chapter 4, while chapter 5 will present the results of the mapping process. The Carpathians show an excellent basis for pro-active conservation, but the time required for collecting scientific and standardised data may be too long for taking management decisions. The results achieved in this study will provide a basis for orienting managers in future decision-making processes. Chapter 6 will explore the adequacy of the spatial resolution used for this kind of study, while in chapter 7 a further exploration for using less detailed baseline environmental data will be done. The considerations about the management of bears, lynx and wolves will be made in chapter 8, assessing the social and political contexts of the study area.

2. THE SPATIAL DIMENSION OF WILDLIFE CONSERVATION

2.1 Introduction

The previous chapter highlighted the importance of conserving biodiversity and the potential offered by the conservation of carnivores. From the review of related variables and threats to biodiversity, the problem emerges of setting targets and selecting specific times and places for conservation action. One of the most basic requisites for applying any conservation practice is the knowledge of the spatial attributes of the target. The simple information of *where* a species lives is vital for any conservation programme to be put in place. Therefore, the spatial distribution of the target is a fundamental characteristic that needs to be known when considering management of natural resources for conservation. This is particularly relevant in programmes that aim to accommodate interests coming from different parties to make the co-existence of wildlife and humans possible, which is the case with carnivore conservation. Generally, when the focus of conservation is animal species, an important factor may be introduced: their ability to move in space. This is relevant in cases of habitat fragmentation, as small fragments may not be enough for conserving species that demand large areas, and the problem may be overcome if connectivity between fragments is present. The analyses of spatial aspects of ecosystems provide the opportunity to consider processes, understand variables that regulate them and develop predictive models.

In this chapter a general introduction of the relevance that the geographical space has in wildlife conservation will be given. This will be followed by the description and discussion of attributes to be considered when dealing with spatial analyses of wildlife. An overview of the mathematical and statistical models used for representing the relationships between wildlife and habitat will be the subject of section 2.4, leading to the integration of GIS and its application in wildlife-habitat models (sections 2.5 – 2.6). The importance of validating models will be discussed in section 2.7. All these aspects are highly relevant to the present study, as each of them was considered during the process of mapping areas suitable for conservation of large carnivores in the Carpathian Mountains.

2.2 The geography of wildlife

Simply stating that the three large carnivores are present in the Carpathian Mountains can have a biodiversity value when considering species distribution at continental scale. However, at regional scale we must be able to say *where* within the Carpathian they actually are and/or may be in order to direct conservation efforts towards the most effective targets. Each species has a characteristic life history, reproduction rate, behaviour and means of dispersion. These determine the way the species interact with the environment and, as a consequence, their spatial distribution.

Stating that a species is distributed over a given area is a limited representation of reality. In fact, our experience of nature represents just one point in a multidimensional and constantly-changing mosaic of animals and plants that are responding to an endless course of social, environmental and climatic changes. There are a series of factors that make the distribution of species highly dynamic. These are of a biological or physical nature, in both the spatial and temporal dimensions (Cox and Cox 1994). Although the *current* distribution of a given species may only be a snapshot of the actual situation, the information is of great importance when conservation plans and monitoring programmes are to be put in place. When the information is further manipulated for predicting distributions and gaps in management practices, the geographical analysis has an increased value. The present work represents a significant contribution to the identification of areas that may need be protected from human activity during the future process of access to the EEC by the Carpathian countries. In order to understand the differences between the depiction of a species' distribution at continental scale and the identification of areas actually and/or potentially occupied by any target species, some concepts related to the species' range and its internal structure will be introduced.

2.2.1 The species' geographic range

The spatial distribution of a species is considered to be its geographic range. A species' range can be defined as the area occupied by its breeding, reproductive populations (Watts 1984). It is characterised by a series of properties of biological, physical and chemical nature and its shape and extent are the result of the interactions of such factors. The influence that external social pressures posed by human populations may have on the specie's range shall not be underestimated, as this can sometimes be fatal. The *actual* range is the region where a species presence has been recorded. This may be different in shape and extension to the *potential* range, which comprises all the areas that have environmental characteristics that make them technically suitable for being occupied by the species (Watts 1984). The actual range may suffer even more severely from the pressures coming from human presence. Gaston (1991) uses the term *extent of occurrence* to represent the areas often considered generally as the species range, as opposed to the *area of occupancy*, which falls within the extent of occurrence but excludes the places not actually occupied by the species (i.e., the actual range *sensu* Watts). The main difference between these two kinds of range, apart from the straightforward one of recorded presence in the area of occupancy, is one of spatial scale. It is very likely that at coarse scale the extent of occurrence is easier to consider than the area of occupancy, which may consist of many isolated patches within it, many of them being undetectable at small geographic scale (Gaston 1991). But more importantly, the area of occupancy is represented by those areas selected by the species among all available ones. It must be noted that the selection can be driven by active preference for some environments over others or it may be induced indirectly by physical or biological factors such as obstacles to free movements (geographical barriers) or competition with other species, including humans (Cox and Cox 1994). In terms of wildlife management the area of occupancy is more relevant than the extent of occurrence, as it brings information about the relationships between the target species and the environment.

Most representations of geographic ranges are maps that only draw the boundaries of areas actually or potentially occupied by a species. Such outputs are very frequently based on data of unknown accuracy and precision, that may be out of date or of a very diverse nature (Karl *et al.* 1999). This technique is a simplification of the actual situation, as it often fails to consider holes within the range boundaries where a species does not occur or islands beyond the perimeter where the species does occur (Brown *et al.* 1996).

2.2.2 The internal structure of the geographic range

The internal structure of a species' geographic range is highly dynamic, being dependent on the relationships between its biological and behavioural characteristics and the biophysical environment both at spatial and temporal levels (Brown *et al*. 1996). A species' range can be continuous or interrupted by so-called *biogeographic barriers* that limit the movement of individuals between places separated by some physical features of the environment. The barrier can be represented by a newly-developed motorway or a wide river, as well as a mountain chain or a cultivated field. Depending on the target species, a spatial feature can represent a limiting barrier that shapes its geographic range or simply a feature that causes the latter to be discontinuous.

Geographic ranges represented by *disjunct* areas may result from long-term climate changes or continental drifts as well as environmental catastrophes (e.g., volcanic eruptions), and human disturbances (e.g., urban developments, motorways, dams).

The risk of isolating populations by habitat fragmentation is directly linked to the risk of extinction, as the size of the patches and the connectivity among patches are the primary variables upon which the viability of a population depends (Gilpin and Soulé 1986).

2.2.3 Corridors

Patches of suitable habitat can be connected by *biocorridors* (hereafter called corridors). A corridor is ‘a linear two-dimensional landscape element that connects two or more patches of wildlife habitat that have been connected in historical time...’ (Soulé and Gilpin 1991).

Corridors give habitat patches the property of connectivity, which can affect both demographic and genetic processes. There are different reasons why connectivity between patches can be vital for wildlife populations, and these are a function of the species characteristics. For example, the size of a single patch can be too small for the population to be viable (Gilpin and Soulé 1986). Examples of corridors in the landscape include hedges, shelterbelts, roads and powerlines (Lavers and Haines-Young 1993).

2.3 Issues of scales in ecosystem management

The degree of habitat fragmentation has reached alarming levels in some areas, sometimes threatening the viability of original wildlife populations (Noss 1987). As the process of fragmentation increases, so too does the conflict between human activities and the preservation of natural habitats. This has driven forward efforts to study the spatial distribution of species and habitats. Particular emphasis has been placed on modelling the species-habitat relationships and the spatial representation of degree of habitat fragmentation. For the management of natural resources to be effective in the long-term, the understanding of species-habitat relationships should be at least at the landscape level (Petch and Kolejka 1993: 42).

The description, study and management of landscapes become difficult when considering the multitude of components that contribute to their functioning (Perez-Trejo 1993). Within the extent of landscapes, the identification of *priority* areas (e.g., those areas with high degrees of biodiversity, see Myers *et al.* 2000), or high development potentials, or where rare species have been recorded, or where economic and political interests are determinant), together with their size and location, has become of paramount importance in any management plan (Stoms and Estes 1993), so as to focus on specific sites that are representative of the landscape's biodiversity. Nevertheless, the focus of a large number of studies during the last few decades has been the understanding of species-habitat relationships at local level. Their contribution to wildlife conservation is vital for the design of any management measure, but the information they provide are seldom applicable to areas other than the one they were described for (Scott *et al*. 2002).

Considering a species across its whole distribution range as the target of conservation practices can be very difficult if the range is a broad one and extends over diverse landscapes, because individual populations may adapt to locally-prevailing environmental conditions. This makes generalisations across the entire species' range difficult (Primack 1998). For this reason, the operational unit for wildlife conservation is often an individual population. Complete wildlife studies should include the processes that take place within the populations' boundary. Although this may seem to be the best possible spatial resolution for conservation activities, in the real world it is very rare to deal with geographically-isolated populations that show clear spatial boundaries.

Therefore, a population may be considered to be either a functional group of individuals (a herd of deer of a pack of wolves), or a completely arbitrary designation dictated by administrative boundaries or landscape units (Soulé 1987). The application is further complicated by the set of biological interactions that produce non-homogeneous spatial distributions even against apparently homogenous landscape units (Gilpin 1987). The selection of spatial scales that are needed to describe a particular aspect of species' range is vital to achieve the objectives of a study. It is very important to note that a *right* scale does not exist, as different scales are suited for different purposes (Trani 2002). The fundamental concept to recognise is that processes occur at all scales at the same time and that phenomena taking place at different scales may interact to produce the final picture that we see at the selected resolution (Levin 1992). Morrison and Hall (2002) define scale as ‘the resolution at which patterns are measured, perceived, or represented’. This implies the fact that scales exist because there is an observer who sets them (Maurer 2002). It must not be forgotten that different factors may drive the processes that occur at different scales (Wiens 1989), so that the variables identified for a particular process may be dependent on the spatial resolution selected.

There are two attributes of scale: the spatial resolution and the extent (Morrison and Hall 2002). The spatial resolution refers to the smallest identifiable unit on the ground, while the extent is the size of the study area. In the process of selecting an appropriate scale for studying a given species, attention should be paid to the species’ biological characteristics (Trani 2002) as different wildlife species perceive the environment at diverse spatial scales.

The trophic level that a species occupies within a community is usually associated with its range size such that species at higher trophic levels have larger ranges. Within the mammals, carnivores’ ranges are the largest (Watts 1984), although this varies according to social organisation and population structures. Thus the same area may be occupied by species with very different requirements and patterns of habitat use, living at different spatial scales, and having very different perceptions of the very same geographical space. Some of them inhabit areas that may include the ranges of many other species, as in the case of large carnivores. Defining the right scale for describing patterns and predicting species occurrence should consider the target species’ home range, seasonal area use and landscape patterns influencing their ecology. Not least, the appropriate scale depends on the study’s objectives (Trani 2002), and applying the outputs of a model developed at one scale at another scale may lead to misleading results (Heglund 2002).

2.4 The species-habitat relationships

The spatial distribution of species depends on their requirement and their response to environmental characteristics (Elton 1927). Traditional wildlife management considers three fundamental physical variables of the environment, which represent basic vital requirements: food, water and shelter (Dasmann 1964). The local conditions and available resources contribute to define the *habitat* of a given species (Morrison *et al*. 1998), and the presence and survival of species are directly dependent on environmental conditions (Anderson and Gutzwiller 1994). The identification of key habitats for wildlife species is essential for development programmes, where drastic land changes could cause the disappearance of some environmental structure (Litvaitis *et al*. 1994)

When sampling wildlife environmental preferences for management purposes, the consideration of all areas occupied by a species can be difficult if basic information about the species' life history are not available. Behavioural studies give a fundamental contribution to conservation and little management action can be successful without knowledge of species' habitat requirements, range size, mating system, and inter-specific relationships (Curio 1996, Sutherland 1998).

Although the description and understanding of all requirements of any species is often impossible because of costs and time involved, some key factors that strongly influence the distribution of many species may be identified and used for modelling the relationships between the species and the environment they live in. The quantification of the relationships between a species and the environment it inhabits represents one of the key aims of environmental management. Species-habitat relationship models give a representation of *goodness* of habitat patches for any target species, and predict the probability of detecting a species, given a set of environmental conditions (Stauffer 2002). They can be developed as binary system (i.e., suitable/unsuitable), ordinal (i.e., high, medium, low) or ratio (i.e., index scores) values (Stoms and Estes 1993). The fundamental assumption underlying these models is that once the key environmental variables have been identified, the distribution of a species can be estimated by knowing the distribution of such variables (Scott *et al.* 1993).

With the relatively recent development of geographic information tools, it has become easier to represent the spatial distribution of environmental variables and produce visual presentation of spatial models as maps of habitat suitability or probability of occurrence of the species. Geographically-explicit models have become extremely powerful tools for representing the species-habitat relationship and they are extensively used in applied contexts for management. A variety of statistical and mathematical models have been developed in the last decades for the representation of species-habitat relationships (Guisan and Zimmerman 2000) and in section 2.6.2 a review of the most commonly used ones will be given.

The present study will make full use of the management and analytical abilities of geographic information systems for modelling the spatial distribution of suitable areas for large carnivores in the Carpathians by adopting a series of techniques for graphically representing wildlife-habitat models.

2.5 Geographic Information Systems and wildlife conservation

Geographically-explicit models are represented graphically as maps showing the distribution of areas associated with different intensities of the relationship being modelled. A map can be considered as an analogue depiction of the Earth's surface that links features in a spatial context. The mapping sciences (i.e., geodesy, cartography and photogrammetry) have developed highly sophisticated tools for accurately recording and representing the location of physical, natural and anthropogenic features and processes, and the rapid development of computing tools has enabled the handling of vast amounts of information coming from remote sensors. One of them is represented by the software that enables the development of Geographical Information Systems.

2.5.1 Geographic Information Systems

Geographical Information Systems (GIS) provide the opportunity for analysing large data sets with quantitative and qualitative approaches. They are nowadays computerised, though the first GIS were nothing other than the superimposition of maps on transparencies for the combination of target variables.

Technically, in a GIS spatial information is stored in a numerical format, allowing a wide range of mathematical and statistical analyses of various degrees of complexity and sophistication (Star and Estes 1990). GIS are tools that can be personalised according to the operator's needs and interests. They can be thought of as static systems if their only purpose is the representation of variables in the spatial dimension, i.e. for producing cartographic maps, or dynamic systems when their analytical potentials are applied to modelling processes in space and time (Stow 1993).

A GIS is typically a system able to store and access data, and can be thought of as a set of working practices, management structures and data organised to use the spatial data-handling functions of a software/hardware system so as to solve a users' problem. Its peculiarity lies in its ability to analyse the set of spatial information so as to obtain output maps that are not simply descriptions of the single elements, but rather are the result of spatial correlation among them (Johnston 1990). This particular attribute of GIS, together with the possibility of combining information coming from diverse sources using the spatial component as relational element, makes it a suitable tool for developing models and simulating processes in diverse contexts.

2.5.2 Relevance of GIS in wildlife conservation

The landscape approach to environmental conservation and management has greatly benefited from the development of efficient GIS, as large areas can now be covered with relative ease offering a synoptic view. The possibility of overlaying maps and developing spatial models that identify environments at various scales has contributed to the progress made in biogeography and environmental management. This led to the development of a trend in predictive geographical modelling in ecology, the core of which is represented by the quantification and geographical representation of species-environment relationships (Guisan and Zimmerman 2000).

GIS has been used extensively in the last two decades for representing the distribution of conservation targets. The identification of biodiversity *hot spots* is one example of a successful application of GIS at global scale (Myers 2000). During the 1980s GIS was used in wildlife conservation mainly for descriptive purposes and production of maps of species geographic range (Johnston 1998), but in the last decade its use has been focused on a more analytical approach, which has then been used, for example, to plan reserve networks (Groves *et al.* 2000) or devise management strategies (Gurnell *et al*. 2002). The analytical system has been improved by the development of software complements that enable the users to address specific issues like habitat fragmentation and wildlife migration (Akcakaya 1995), potential vegetation mapping, and environmental impact assessment (Corsi *et al.* 2000).

2.6 Wildlife-habitat models

The relevance of mapping environmental suitability for some key species for the conservation of biodiversity appears evident and the practice of developing wildlife-habitat models has given a significant contribution to such practice. Wildlife-habitat models can be of different nature and be produced adopting different approaches, depending on the objectives of the study and the available data. The present study uses GIS-based modelling for mapping conservation areas for carnivores in the Carpathians and the technique adopted has been selected among a variety of available ones. In the following sections I will review some of the most common types of models.

2.6.1 The modelling approaches

A wide variety of statistical models is currently in use to represent and simulate the spatial distribution of terrestrial animal and plant species as well as biomes and processes, and GIS are being increasingly used to model wildlife-habitat relationships (Davis *et al.* 1990, Scott *et al.* 1993). The selection of significant parameters is essential for successfully model any process, thus the identification of causal variables is the most critical step in model development (Guisan and Zimmerman 2000).

Models used in ecology have been classified repeatedly using different approaches, but the main differences are consistent throughout different classifications. Stoms *et al.* (1992) define both deductive and inductive approaches for modelling wildlife habitat with GIS. Their classification is comparable to the one offered by Loehle (1983), which recognises two types of models: calculating tools (inductive *sensu* Stoms *et al.*), empirical models intended to describe the configuration of the real world (Guisan and Zimmerman 2000), and theoretical models (deductive *sensu* Stoms *et al.*), synonymous with the mechanistic ones in Levins' (1969) classification, that are capable of predicting scenarios from knowledge of causal variables and relations (Guisan and Zimmerman 2000).

In the deductive approach, the environmental requirements for the target species are known *a priori* and suitable habitat is identified through mapping the distribution of environmental characteristics. The output is a map of the distribution of *potential* habitat for the species, as the actual presence of the species at each location needs to be verified after modelling (Stoms *et al.* 1992). The inductive approach describes the relationship between the target species and the environment by direct observation of environmental characteristics of locations where the species' presence has been recorded. This approach is frequently used in empirical models *sensu* Levins (1969), the major aim of which is to understand the actual geographic distribution of a species rather than project its potential one according to established parameters. In this case the importance of having a measure of accuracy of the species' locations used in the model-building process appears evident (Stoms *et al.* 1992). This is not a trivial issue and will be discussed in section 2.7.

2.6.2 Spatial models for wildlife conservation

Wildlife-habitat models are developed upon the assumption that predictable relations exist between the occurrence of a species and some selected variables of the environment (Heglund 2002). In addition to being inductive or deductive, models can be descriptive or predictive (O'Connor 2002). The former aim at estimating a qualitative/quantitative relationship between the species' presence and some environmental variables in known areas and use such relationship in order to predict the species presence in unsurveyed areas. The predictive models are expressed in probabilistic terms and aim at predicting changes in specie's distribution under variable environmental conditions (O'Connor 2002). The majority of wildlife-habitat models fall into the first group. Such models can be used for habitat evaluation in areas subject to development, with the aim of minimising the impact on wildlife and selecting areas essential for wildlife survival (Scott *et al.* 1993).

2.6.2.1 Habitat Suitability Indices

In the last decades there has been a considerable amount of work done towards the identification of relationships that would express how species relate to the environment, thus guiding towards the conservation of particularly valuable areas. One approach used extensively for this purpose is the development of *Habitat Suitability Indices* (HSI). They were developed by the U.S. Fish and Wildlife Service (USFWS) in the attempt to establish linear relationships between species and environmental variables (Conway and Martin 1993, Donovan *et al.* 1987, Duncan *et al.* 1995, Thomasma *et al.* 1991) in a standardised way across all the United States (U.S. Fish and Wildl. Serv. 1981).

HSI are models that incorporate a number of environmental variables considered to be important for the presence of a given species. They are related to the species presence in a quantitative way using data from field studies and combined spatially in a GIS (Donovan *et al.* 1987). Despite representing a step towards standardisation and objectivity, the HSI contain a great deal of subjectivity in various steps of their development. The selection of significant variables is left to subjective decision by scientists and experts who have conducted field studies (Scott *et al.* 1993). More importantly, the weight that each variable is assigned can be highly subjective and strongly location-dependent (Heinen and Lyon 1989). The applicability of the models is therefore restricted to specific areas and generalisation can hardly be done unless the model is developed upon information coming from a large number of sites throughout the species' range (O'Neil *et al.* 1988).

Habitat Suitability Indices are combinations of regressions between an environmental variable thought to be a limiting factor for the species' survival and the species presence according to scores associated with each variable by experts studying the target species. Although HSI are only simple models that tackle the multivariate nature of wildlife-habitat relationships as a series of univariate components, their development has represented a starting point for a whole set of models recently developed for mapping potential distribution of species. The major limitation of conventional HIS is that they assume linearity between the species presence and each environmental variables, condition rarely met in nature (Heglund 2002). Their use has strongly been criticised because of the lack of a validation process that could assess their reliability. They are not usually represented as maps, but rather as regression lines and/or equations.

Coupling GIS and HSI enables the extrapolation of environmental characteristics over inaccessible areas and the interpolation and representation of the models across extensive regions, assuming the model is suitable at such a scale. Furthermore, the integration of GIS in the development of HSI has enabled the consideration of environmental heterogeneity over large areas and the incorporation of biophysical variables that are otherwise difficult to measure (i.e., topography, distance from landscape features etc.). This has represented an advance in the consideration of the whole species' range and its internal structure, in an exercise called *Habitat Evaluation Procedure* (HEP) that includes basic information on a number of species in a generalised way so as to model environmental changes following the alteration of few variables (Williams 1988).

Including HSI in management plans at regional level is very important, because they can guide the identification of critical areas for the survival of endangered species. For example, Conway and Martin (1993) suggested that the best management practice of woodlands in Arizona should consider the selective conservation of large dead tree trunks, required for nesting by Williamson's sapsucker (*Sphyrapicus thyroideus*), as revealed by development of the HSI.

The spatial scale at which the HSI are applied within a GIS is important because inappropriate scales would fail in the identification of small patches of highly-suitable habitat for species that use small areas (Duncan *et al.* 1995). Baker *et al.* (1995) noted that the investigation of habitat suitability should be made at different spatial scales. Their study on sandhill crane (*Grus canadensis tabida*) habitat benefited from the use of GIS tools at all stages, from selecting sampling points to spatially interpolating habitat characteristics and modelling the HSI at five resolutions. The authors pointed out that restricting the analysis to the areas known *a priori* as being potentially suitable (i.e., wetlands in this case) would save time and contribute to a better understanding of the species' ecology.

Habitat Suitability Indices can be used for modelling the impact that environmental changes may have on the target species. Pereira and Itami (1991) used HSI for red squirrel in Mt. Graham, Arizona, to assess the potential impact a project for constructing an observatory in the area would have had on the squirrel' habitat. The study was also an opportunity to test the HSI with data collected in the field rather than through expert knowledge. The authors initially used univariate analysis for selecting those variables to be included in the model. Logistic multiple regression was then used for developing an environmental model that was subsequently integrated with a trend surface one in a Bayesian approach, adding a probabilistic component to the modelling procedure, and tackling the issue through non-linearity approach. Kliskey *et al.* (1999) simulated the impact of different forest management scenarios on the landscape using HSI for marten (*Martes americana*) and caribou (*Rangifer tarandus*) over a period of 120 years. The process included an HSI testing phase that suggested some additional variables may be included in the model, although the quality of data used for testing was not optimal.

Another significant limitation of HSIs lies in their inappropriateness for generalisation. They are usually built on information collected over restricted areas and the resulting wildlife-habitat relationship may well be highly site-specific. The application of HSI on large areas, at the regional or state level, is often difficult and leads to large commission errors (areas where wildlife presence is predicted but not detected; Block *et al.* 1994). Evaluation of HSIs is essential before they can be used by wildlife managers, and testing should be done using as many study sites as possible, in order to account for most of the species' ecological valence (O'Neil *et al.* 1988).

2.6.2.2 Gap Analysis

Notwithstanding the limitations of the HSI, they were extensively used by the USGS Biological Resources Division when the innovative Gap Analysis Programme (GAP) was launched in the early 1990s as a mean for identifying areas with high biodiversity lacking appropriate protection (Scott *et al.* 1993). GAP uses GIS mapping procedures for giving a quick overview of the biodiversity conservation status of large areas by overlaying vegetation maps and distributions of some biodiversity indicator species (i.e., butterflies and some vertebrates). The objective of the programme was to identify gaps of protected land within areas of high biodiversity at a regional scale (Scott *et al.* 1993). Known wildlife distributions were interpolated in areas not surveyed relying on the assumption that vegetation composition and structure can be used as proxies for wildlife presence under the relationships established by the HSI (Edwards *et al.* 1995).

The approach was new in its consideration of landscape-sized samples, as opposed to the more common local views where single species were considered over small areas. Although appropriate for the magnitude of the project (state-wide across the U.S.A.), it must be noted that, at a local level, the analysis may fail in considering the internal structure of ranges that fall entirely within the Minimum Mappable Unit (Tamis and Zelfde 1998), which was set accordingly to the objective of continental mapping at 100 ha. Nevertheless, the advantage of the whole exercise is to provide a general baseline map that will serve as starting point for detailed studies at local scales and the spatial resolution and the extent adopted satisfied the objectives set (Scott *et al.* 1993). In this context, the present study represents a valuable contribution in this direction, through the production of baseline maps that will represent the spatial distribution and character of areas associated with different degrees of suitability of the presence of large carnivores, used as proxies for biodiversity.

The product of GAP is a map of areas with high biodiversity that are lacking legal protection. The visual representation is extremely powerful and valuable for management purposes. Notwithstanding the many limitations it has, GAP still represents one of the greatest attempts in the assessment of biodiversity conservation status across broad areas, because it integrates GIS with habitat models and remotely-sensed data to provide the basis for setting up conservation projects at local and regional scales (Jennings *et al.* 1997). The benefits of such an approach were pointed out by Davis *et al.* (1990), who underlined the urgent need for a biodiversity conservation information system. The integration of information from different sources and in different formats can sometimes prove difficult, but it represents the only way that such sparse information can be possibly used (Davis *et al.* 1990). This is also addressed in the present study.

2.6.2.3 Continuous models

The representation of habitat suitability has often been modelled with a deductive approach producing deterministic discrete models (e.g., HSIs). The real world is very rarely structured in a discrete manner and, particularly when considering environmental characteristics, the continuous distribution and regionalised behaviour of variables should be taken into account. For this reason, continuous models based on probability theory and fuzzy logic tend to be preferred by ecologists (Hill and Binford 2002).

In the process of developing a model to assess the distribution of wildlife habitat, the initial steps that contribute to the establishment of rules to follow in the decision-making phase are particularly critical because they drive the interpretation process once the output is produced.

As already mentioned for the development of HSI, the first problem to tackle in any modelling process is the selection of environmental variables to include in the model. These are often chosen based on the knowledge of field experts and sometimes a set of univariate regressions are used for eliminating redundant variables or to establish the relationships between each variable and the species' presence or abundance (Schamberger and O'Neil 1986). The implication with this procedure is that correlated variables may yield significant regression results and are incorporated in the model as independent variables, while the contribution of one of them is redundant because the variates are actually co-variates (i.e., they are correlated). The use of multivariate statistics is more appropriate for tackling problems that obviously are of multivariate nature (Manly 1994, Sokal and Rohlf 1995). Nevertheless, it must be noted how multivariate statistical inference can sometimes give misleading results. Rexstad *et al.* (1988) indicated that the interpretation of coefficients from multivariate procedures is often arbitrary and meaningful *a priori* ecological thinking can very rarely be replaced by sophisticated multivariate statistics techniques. Multivariate statistical methods often require that data meet rigid assumptions, but in some cases the biological justifications of some broken assumptions may be used (O'Connor 2002).

Methods for selecting variables used in multivariate modelling include both inductive and deductive approaches, as well as mixed approaches. Herr and Queen (1993) considered expert knowledge-based information and calculated some variables in an inductive manner from plotted nest locations of sandhill crane in a GIS. A set of chi-square tests were performed for checking significant differences in the distributions of expected and observed sandhill crane nest locations with respect to each variable considered at a time. The authors recognised that this step-wise process would not be appropriate as some of the variables that were considered were correlated, thus they performed a general chi-square using only a combination of few selected variables.

Once the variables are selected, the modelling approach can be of probabilistic nature or fuzzy logic, depending on the approach adopted, and more often, on the data available for building the model. Augustin *et al.* (1996) developed an autologistic model for predicting the presence of red deer in Scotland using data scattered across the area and calculating the probability of presence in each cell of the digital data set by interpolating from data in neighbouring cells in a deductive manner. The authors present two supplementary methods for estimating probability of occurrence of deer in each cell, including the Gibbs sampler - which gives estimates in a reiterative way for each cell - and a combination of the autologistic and Gibbs methods. The main advantage of such an approach is the consideration of autocorrelation between locations where the presence of wildlife is recorded. This is particularly important for species that live in big groups, such as deer herds. The advantage of the Gibbs sampler (as well as any other re-iterative sampling method) is the ability to amplify the data set, thus offering the opportunity to estimate the accuracy of the model.

An inductive approach assumes that the environmental variables are not known *a priori*. A GIS can be used for extracting such variables from known locations of the target species. A principal component analysis could successively guide the reduction of dimensionality of variables to be modelled (Buckland and Elston 1993).

The availability of wildlife data in a presence/absence format sometimes makes their use for statistical analyses difficult. Methods often used, such as that generalised linear models (GLM) are not usually able to estimate satisfactorily the distribution of wildlife populations as successfully as a simple count of individuals would (Guisan and Zimmerman 2000). Nevertheless, Buckland and Elston (1993) successfully modelled red deer (*Cervus elaphus*) census data in Scotland using a GLM with a logistic link function, that could be built with data of presence/absence.

Walker (1990) used logistic regression to map the distribution of three kangaroo species in Australia against climate parameters. The model was built with an inductive approach using a Classification and Regression Tree (CART) function within a GIS that established decision-rules, as well as a probability function (logistic regression model) for mapping the probability distribution of the species. A comparison between the two methods revealed that commission error (areas where presence of kangaroos was predicted but not recorded) was higher with logistic regression than with CART.

Multivariate techniques are more frequently used in inductive approaches rather than deductive, as the extraction of basic information from wildlife location is relatively easy. Aspinall (1992) used deductive spatial modelling based on Bayes' theorem for describing the distribution of red deer in Scotland. The method assumed *a priori* probability of the presence of particular environmental characteristics by estimating the probability of their occurrence in observed red deer presence/absence locations. The variables to be included in the model were selected using chi-square tests for presence against random locations. The model produced a probabilistic habitat suitability map with an overall accuracy of 70%, when compared with census data for red deer. The main limitation of this approach is a methodological one in that Bayes' theorem assumes independence between covariates, a condition rarely met in ecology.

A number of wildlife studies that have successfully applied a multivariate method based on the concept of similarity to some optimal conditions, classifying regions according to the distance to a given set of environmental conditions. One such method is the Mahalanobis distance, which will be used in the present study. The method is commonly used to assess environmental suitability as indicated by the distance of each point in the area considered from a reference point that represents the *optimum*. It also can be used for guiding the selection of predictor variables by the maximisation of the Mahalanobis distance between known *good* and *bad* areas (Johnson *et al.* 1998). Hill and Binford (2002) define the models based on distance classifiers as belonging to the fuzzy logic family, as they do not use the probability theory, but rather the decision rule is based on the concept of similarity.

The Mahalanobis distance was successfully used for mapping potential suitable habitat for black bear in Arkansas (Clark *et al.* 1993), grey wolf in Italy (Corsi *et al.* 1999) and large carnivores in the Alps (IEA 1998) and in the Scandinavian Peninsula (Støbet-Lande *et al.* 2003). The method builds an inductive model from wildlife observations plotted on maps of environmental variables within a GIS. The areas actually occupied by the species are assumed to represent the optimum combination of environmental parameters for that species. This is a strong assumption that will be discussed in chapter 5, when evaluating the strengths and weaknesses of the method adopted in the present study. The Mahalanobis distance then uses this *optimal* combination to predict species distribution. The training data required to build the model do not have to be in the format of presence/absence. This is an advantage, as absence data are difficult to record. The values obtained are dimensionless as they are a function of standardised variables. The technical details of this method will be given in chapter 5.

A deductive-analytical model was developed by Pereira and Duckstein (1993) using multiple-criteria decision-making (MCDM) techniques for assessing land suitability. The authors found the methodology to be suitable for overcoming the limitations often present in land suitability approaches: inappropriate data scaling and lack of independence among factors. Compromise programming was used to identify the set of optimal conditions. The Mahalanobis distance was then used for estimating degrees of suitability as represented by distance values from the optimum point. The method was used to assess habitat quality for the endangered Mt. Graham red squirrel in Arizona.

Knick and Dyer (1999) used the Mahalanobis distance for estimating habitat suitability of black-tailed jackrabbit (*Lepus californicus*) in South-western Idaho. The results obtained were validated with an independent data set and found to well represent the distribution of areas where jackrabbits were found. The authors emphasise some of the limitations associated with the method, which were highlighted in a previous work (Knick and Rotenberry 1998). Such limitations are generated by the use of a set of presence data that is assumed to represent the optimum combination of the variables considered. This is a strong assumptions that may produce misleading results when data on species' presence are collected over areas that are not optimal. This will be further discussed in chapter 5. In this case, the outputs of Mahalanobis distance may consider optimal areas as being different from the mean 'optimum' vector, resulting in large omission errors (Knick and Rotenberry 1998, Rotenberry *et al.* 2002).

In spite of such limitations, the method has proved suitable for applications with data sets recorded at different scales and it is particularly useful for species with large ranges and generalised habitat requirements such as large carnivores (IEA 1998).

Hirzel *et al.* (2002) recently proposed a multivariate method that takes into consideration the n-dimensional niche and estimates that a habitat suitability probability map is the one based on the comparison between the characteristics of presence areas and the whole study area. In principle, it is very similar to the

Mahalanobis distance method, but it gives a weight to the different environmental factors through their vectorial dimensionality, thus accounting for the ecological characteristics of the species.

New techniques for the estimation of wildlife habitat suitability are continuously being explored, sometimes borrowed from other disciplines. One of them, very little explored in this field, is the Artificial Neural Network (ANN). The main strength of ANN is that they assume neither data normality, nor linearity in the response of wildlife presence to environmental variables (Lek and Guégan 1999). Nevertheless, their ability to produce accurate predictions is very much dependent on the training data, and Lusk *et al.* (2002) found that a high variability in the training data may cause the ANN to perform poorly when compared, for example, with a multiple regression model.

2.7 Model evaluation

Modelling wildlife habitat in a GIS has some intrinsic limitations that are mainly related to data quality. Although a range of models has been developed for a large number of species, their application for management and conservation practices is still restricted by lack of testing and validation (Schroeder and Vangilder 1997).

2.7.1 Sources of error

Input error associated with every information layer is kept in a GIS and it contributes to the model output overall error. Sources of error in GIS modelling are present at different levels and in various forms (Burrough and McDonnell 1998). The accuracy of the base maps is particularly important for highly developed areas, where the landscape changes rapidly as a consequence of human impact. Depending on the variables extracted from the base maps, the dating of maps can be of variable relevance (Guisan and Zimmermann 2000). Maps are frequently used as source data and the process of digitising paper maps brings a considerable error that results from the distortions caused by the physical nature of the paper and the digitising process (Burrough 1986).

Other errors in the data used for building models include the density of observations and their positional accuracy; as well as the variation brought by different people collecting the field data. Data input is frequently associated with errors and cross-checking by different people may be advisable. Map scale and spatial resolution are sources of error that need to be taken into consideration, as any spatial model will provide an output with a spatial accuracy equal to the smallest scaled input data layer (Star and Estes 1990). Geographic projection and coordinate systems are associated with errors, and when data layers originally created in different coordinate systems are overlaid, the coordinate conversion process is made through an interpolating algorithm, bringing in some error. When layers at different spatial scales are used, they need to be interpolated to the same scale and in order to be used for modelling, they frequently need to be in raster format. Re-scaling and rasterising are forms of interpolation that have usually some combined errors (Burrough and McDonnell 1998).

Single operations such as map overlays are associated with errors, and the operation itself assumes that the input maps are perfect representations of the real world, a condition rarely met (Arbia *et al.* 1998). Wildlife models are often built upon expert knowledge, itself a source of subjective interpretation and error. The presence of error is therefore inevitable in environmental modelling with a GIS, but, as long as this error is defined and is acceptably low, it is a minor disadvantage greatly out-weighed by the advantages a model output represents. However, it is important to consider as many sources of error as possible and quantify the input error associated with each one of them, possibly including the potential multiplication and propagation effects that GIS operations are associated with (Heuvelink 1998).

2.7.2 Model Validation

Once the model is applied to an area, and the habitat patches are rated for their suitability, field surveys can be made to check for the species' presence and only at that stage should any management decision be taken (Stoms *et al.* 1992).

HSIs have been developed for over 160 species across the USA, but they have rarely been validated. Donovan *et al.* (1987) proposed a test for validating HSI for the fisher (*Martes pennanti*) in Michigan. The authors made a field survey and calculated a Preference Index (PI) by ratioing the percentages of habitat use and availability within each HSI class. The HSI and PI were overall positively correlated, although some differences emerged according to habitat types (i.e., pine plantations had high HSI but were poorly used by fishers). This suggests how site-specific the HSI are. Because of the nature of HSI, where the variables that determine the outcome need to be known *a priori*, its cartographic modelling should be considered as a hypothesis-formulation process rather than a scientific truth achieved by a hypothesis-testing procedure (Johnston 1998).

Schroeder and Vangilder (1997) tested a set of HSI for five different species, all based on oak-mast production. Field surveys and monitoring of oak-mast production in two areas in Oregon were used as testing data sets. The authors concluded that the 5 HSIs were positively correlated with the oak-mast production model they developed, but suggested the HSIs may be modified with the inclusion of oak canopy closure variable.

Duncan *et al.* (1995) validated the HSI for Florida scrub jay using data on the species' demography from three successive years, acknowledging the potential stochastic variability associated with wildlife demography. The areas associated with high suitability correlated well with the demography of the jay, and the authors suggested that the use of demography data could be useful for identifying potential population sources and sinks[1], thus guiding the wildlife managers towards selective protection of areas that may have different demographic roles.

Detailed data on a species' demography are often not available to model developers and wildlife managers, making this kind of validation process sometimes difficult. Particularly when models are developed with an inductive approach, the presence/absence data are often the only available ones and they are used for extracting the information about wildlife-habitat relationships. The validation of such models can then be performed either using newly collected field data or expert knowledge. The former option is usually very expensive and time consuming, while the latter may be site-specific and very subjective. In the present work it was possible to collect independent data for validating the outputs produced through an intensive field campaign. The methods and results of validation will be explained and presented in chapters 4 and 5.

Model validation should always be performed because the recognition and quantification of errors is a vital requisite for robust model development. The validation phase should be part of the modelling process, ideally at all stages (Morrison *et al.* 1998). When applied for management, models should be used considering their ability to reproduce the real situation and their major limitations

[1] The concept of population sources and sinks refers to areas where the population is healthy and can successfully reproduce (a source). This produces individuals that can locally disperse into areas with lower habitat quality, and potentially undergoing processes of local extinction (sinks), where the dead individuals are replaced by new ones coming from the source instead of being replaced by new locally-born ones (Pulliam 1988).

(Guisan and Zimmermann 2000, Morrison *et al.* 1998). This ensures no misleading interpretations are made (Block *et al.* 1994).

2.8 Conclusions

The consideration of the spatial distribution of priority areas for conserving biodiversity is particularly relevant when efforts are being made for preserving and integrating wilderness needs with human economic and social demands on the land. The EU has highlighted the need for a pan-European approach to Biodiversity conservation that is based on transparent, consistent and accountable approaches, thus encouraging the development of management tools (EU 2001). These are continuously calling for rules that enable managers to make decisions within an ecologically sound and scientifically robust approach. This has stimulated the development of a series of mathematical and statistical models that may contribute to the production of pragmatic management plans.

Models are a simplification of the real world and as such they should be used with caution and with cognition of their limitations and associated errors. Notwithstanding their limitations, they still represent a very effective tool for understanding the processes and generating hypotheses to be tested. A plethora of techniques has been developed and each one of them may present limitations that make it more or less suitable for any application, depending on the data set available and the purpose of the modelling process. Reliability of models depend on many factors, starting from the spatial scale at which they are developed and applied, up to their ability to represent the real world, assessed through a validation phase.

In the light of the issues discussed in the previous sections, the aim of the present study is to contribute to the selection of priority areas for the conservation of Carpathian biodiversity. This will be done through the development of a model for the distribution of conservation areas for large carnivores in the Carpathian Mountains, assessing its robustness at different spatial scales as well as its reliability for predicting the real situation. These will be achieved by validating the outputs against an independent data set. The accomplishment of such aim was reached through the achievement of a number of objectives throughout the study. They are outlined below:

- *Establishing contacts with collaborators and interest groups in the target countries.*
- *Being integral part of the effective network of scientists and experts within the Carpathian Ecoregion.*
- *Populating the data base on environmental variables and carnivore presence*
- *Carry out a field campaign in the area and collaborate with local partners in the production of geographical data.*
- *Standardising the data across the Ecoregion to obtain one ecoregional cover for each variable.*
- *Reclassify and validate Land Cover data.*
- *Create and validate species-specific reception regions using techniques of map algebra.*
- *Define environmental suitability classes for each species using the Mahalanobis Distance classifier.*
- *Acquire and pre-process satellite images at 1km and 30m resolution.*
- *Organise and carry out Validation field campaign (The Carpathian Expedition).*
- *Define environmental suitability across spatial resolution and estimate differences.*
- *Pre-process time series of images for unclassified land cover data.*
- *Map and compare results obtained with classified images and vegetation index.*
- *Analyse distribution of existing protected areas in relation to the estimated suitability areas for the three carnivores.*
- *Estimate potential conflicts with human activities across the whole Ecoregion.*
- *Estimate potential conflicts with shepherds over a subset of the study area at 30m resolution.*
- *Discuss results for management purposes.*

Once the objectives will be achieved, the study will represent a contribution to the understanding of the relationship between large carnivores and the environment in an area poorly studied and where wildlife is conserved in relatively good conditions. The next chapter will describe the study area and the methods used for analyses, and introduce to the ecology of the three target species.

3. STUDY AREA AND TARGET SPECIES

3.1 Introduction

One of the primary objectives of the present study is to identify the areas that are potentially suitable for the conservation of large carnivores across a wide area of Europe. There are at least two critical issues to be considered in the process of mapping such areas. One is represented by the biological aspects of European large carnivores' populations, their distribution across different countries, their environmental requirements, conservation status, and the impact that human activities may have on their survival. The other is represented by the geographical characteristics of the target area. Large carnivores use extensive areas and need wide ranges as a minimum life requirement. Large areas of land are rarely homogeneous, particularly so in Europe, where the landscape has been largely modified and human development has strongly fragmented the natural habitats.

The challenge in understanding and identifying processes to be maintained in order to conserve biodiversity is a complex one that cannot be answered unilaterally through a single-species, site-specific or unidisciplinary approach. There is a strong necessity for international collaboration and interdisciplinary studies in order to provide solutions to complex problems such as biodiversity loss (NERC 2002). The present study has a strong interdisciplinary character, as it needs the integration of quantitative biology and quantitative geography, as well as offering opportunities for the involvement of qualitative social, cultural and political issues. A purely biological analysis would not produce the same output if the geographical aspects were neglected, thus no spatial characteristics would be considered. At the same time, the geographical analysis is only meaningful if integrated with biological information on the target species, thus requiring a particular effort in considering various aspects of both the area and the wildlife species considered.

The study area comprises the Carpathian Mountains in Central Europe, where almost one third of the European large carnivore population remains relatively intact because of the presence of extensive forested areas and the strict management this region experienced while under dictatorial communist rule. This chapter gives a description of the Carpathians, with a characterisation of their ecosystems that spread across seven countries.

An introductory presentation of the biology of three species of carnivores will also be given: the brown bear, the European lynx and the grey wolf. These three species, together with the otter and the wolverine, are the only large carnivores in Europe. They roam across wide areas and pose challenging questions for their conservation, as they are often in conflict with human activities.

Finally, an overview of the populations of the three carnivore species and their conservation status in the Carpathian Region will be given, thus highlighting the underlying need for the pro-active conservation approach adopted by the present study.

3.2 The Carpathian Mountains

The Carpathians are the second largest chain of mountains in Central Europe after the Alps, and the largest in central-eastern Europe. They spread from the Danube River area of Slovakia, northwest of the capital city Bratislava, to the Iron Gate on the Romanian Danube at their south-eastern end (Fig. 3.1, Voloscuk 1999), covering an area of approximately 200,000 km^2 (and extending for 1,300 km).

Relatively low human population densities, difficult access to many mountain ranges, and a considerable number of large forests have allowed a rich and diverse fauna to exist in the Carpathians, including substantial populations of large carnivores.

The mountain complex is divided among seven countries: Austria, the Czech Republic, Slovakia, Poland, Hungary, Ukraine and Romania (Witkowski 1999). More than half of its extent (55%) lies in Romania, while smaller proportions are in Slovakia (17.1%), Ukraine (10.3%), Poland (9.3%), Hungary (4.3%), Czech Republic (3.2%), and Austria (0.3%) (Groch *et al.* 2000). This study focuses only on countries that contain at least 5% 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 large carnivores population. Hence, the geographic range of this study is limited to the Carpathian area of Poland, Slovakia, Ukraine and Romania, which together contain 90% of the Carpathian chain.

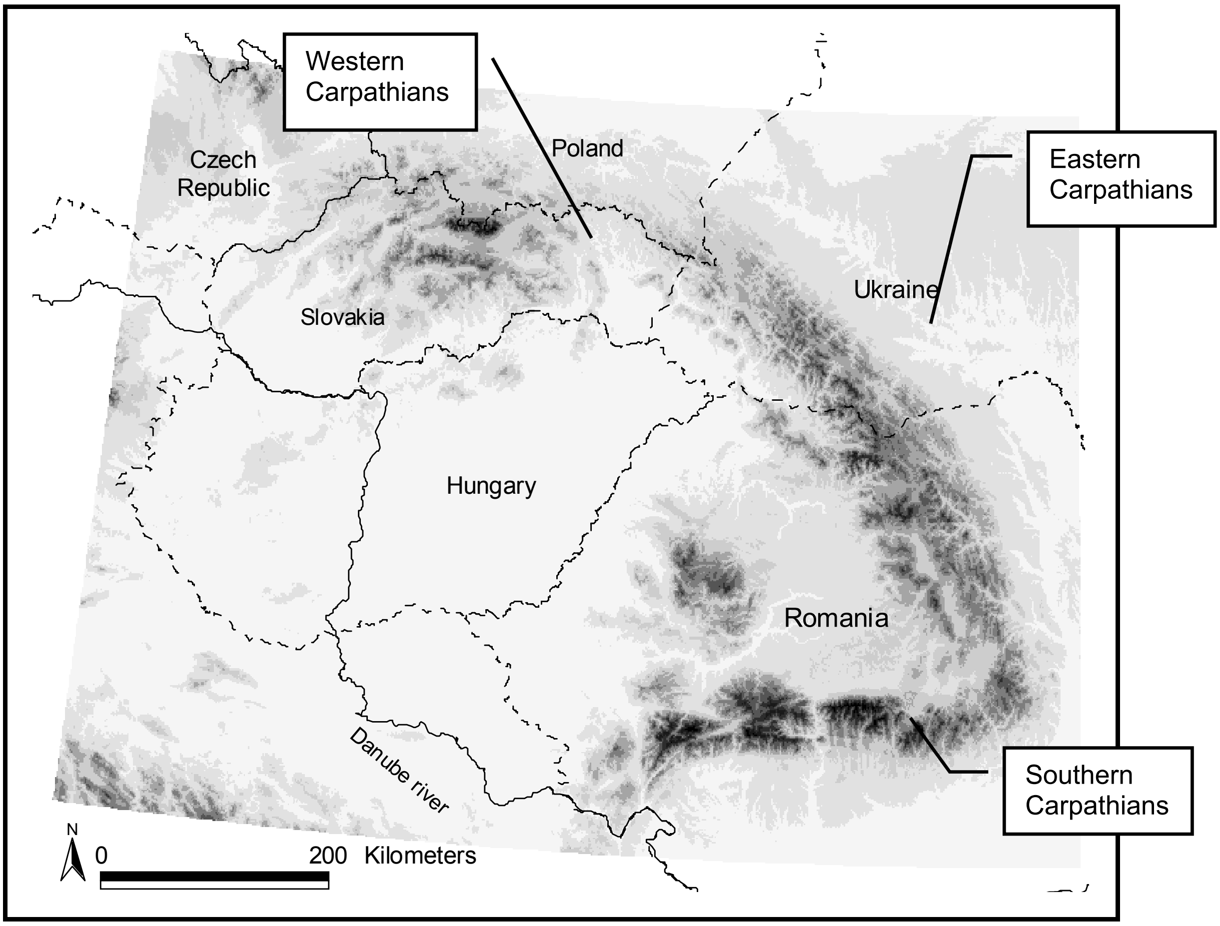


Figure 3.1 – The Carpathian Mountains. Grey shades represent altitude as provided by the USGS TOPO30 dataset, while broken and continuous lines represent and country boundaries and Danube river, respectively.

Geomorphologically, the Carpathian region is formed of two parts: the Carpathian Mountain Arc and the enclosed interior-basin area. The mountain arc presents two belts: the inner and the outer ones. The orogenic movements that contributed to the formation of the Carpathian arc started in the late Mesozoic times, with a movement from the interior towards the exterior, and northwards. It finally ended during the late Miocene times. The Mountain arc can be divided into three regions (see figure 3.1): the western Carpathians in the north-west, the eastern Carpathians in the north-central east, and the southern Carpathians, mostly developing in the east-west direction. The southern area is geologically different from the other two, and much younger, thus probably resulting from other orogenic movements (Földvary 1988). Most of the ranges are richly forested and, as a result, there has been an extensive timber industry for centuries.

The productivity of Carpathian forests is high and some countries use the wood resource for economic income. Most of the forests are mixed oak and beechwoods, that give way to spruce and pines at higher altitudes. The Carpathian beechwood is particularly productive, and seeds are recorded to be heavier than in other areas, probably due to the rich soil (Zarzycky 1964). The preservation of the area in its natural state has to be attributed to the past communist rule, that exercised a strict control over public land (all rural territory belonged to the State). Problems arose after the collapse of communism, when fast economic growth was sought at the expenses of the natural resources of the land. In addition to this, privatisation and urban development increased forest fragmentation and reduction (Soran *et al*. 2000). This situation represents a great threat for the preservation of the Carpathian forests, as they are one of the last large mature forests in Europe.

The Carpathians have a high number of endemism (organisms that are only distributed in the area), due to their role as a north-south corridor during the glaciations period. Ice would have reached the pre-montane areas of Poland, and many species would have survived the low temperature by using the mountain complex to move towards southern lands (Witkowski 1999). This caused the composition of a unique ecosystem that persisted over the centuries after the glaciations. Such a peculiarity, stimulated the inclusion of the *Carpathian Ecoregion* in the list of the 200 Ecoregions defined by the World Wide Fund for Nature (WWF), thus including the Carpathians in the list of targets of conservation actions at national and international levels (Olson and Dinerstein 1997).

Although the Carpathians extend across different countries, the majority once belonged to the Austro-Hungarian Empire, and thus have similar historical backgrounds with respect to some cultural habits (Witkowski 1999). Hunting of wild species is an example. The hunting tradition in Poland, Slovakia, Ukraine and Romania is deeply rooted in the culture of local people and hunting activities are regulated by structured legislation. The majority of the forested territory (up to 80%) of Poland, Slovakia, Ukraine and Romania belong to their respective States, and so do the wildlife that live in them. The territory of each country is divided into hunting management units, called Hunting Grounds (HG). These cover different areas in different countries (area ranging from 2,500 to 10,000 ha), but the approaches to their management are consistent across the ecoregion.

In order to define a specific area, the Carpathian Ecoregion has been described to extend within boundaries set by Kondracki (1978) according to its orographic characteristics (Fig. 3.2).

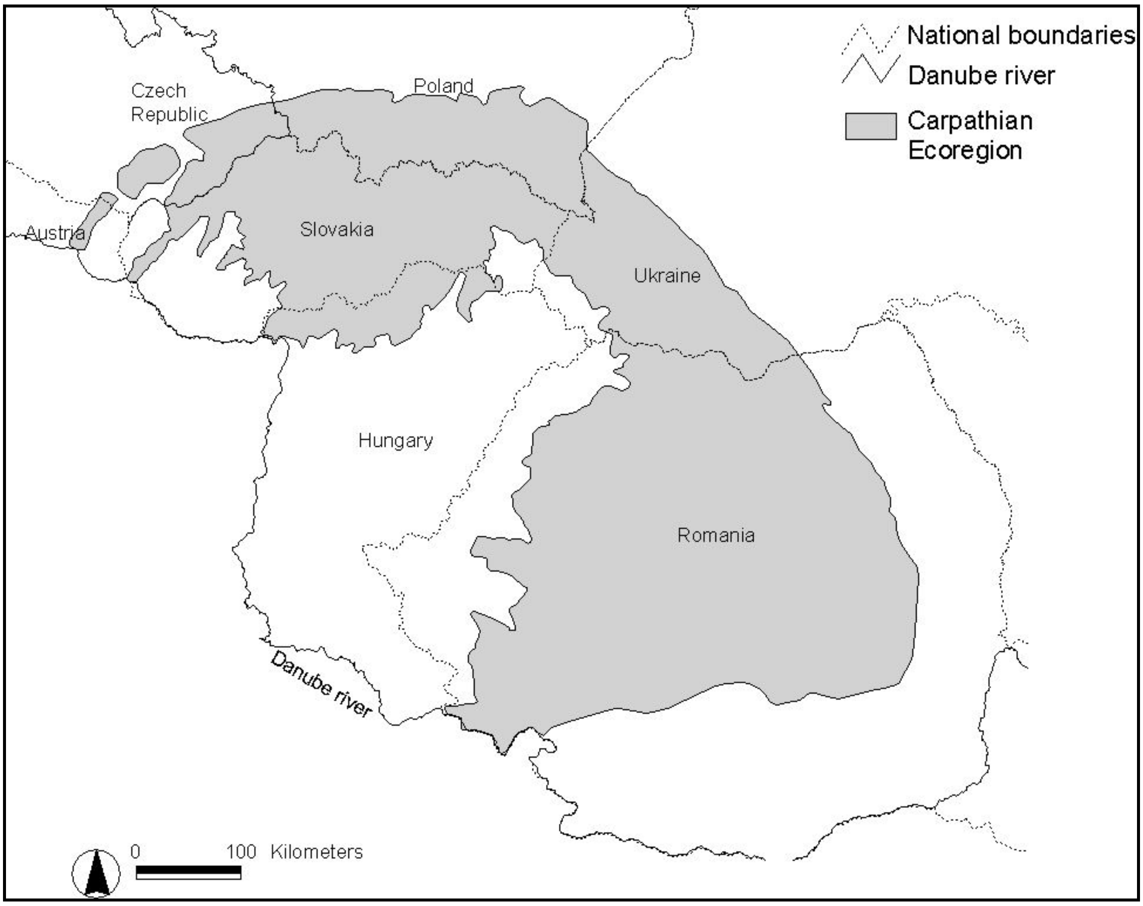


Figure 3.2 – The boundary of the Carpathian Ecoregion as set by Kondracki (1978) according to its orographic characteristics.

The economy of the countries is highly rural and economic development is mainly focused on the tourism industry (Groch *et al.* 2000) and land development, such as construction of large dams, conversions in land use and agriculture practices and urbanisation (Witkowski 1999). Such development would certainly cause a loss of forested land and high fragmentation of forested areas.

The Carpathian Mountains are not an island of wilderness without human activities. Traditionally, millions of rural people make their living in the forest and valleys of the region by using rural methods. Despite the separation represented by national boundaries, Carpathian people are united by a strong and common cultural heritage. During recent years, the picture is changing and the region is facing a mounting pressure. Overuse of natural resources, deforestation and fragmentation of habitats, pollution, increasing tourism and transport development, amongst others, will have a negative impact on wildlife, which will be forced to survive in this human-dominated and fragmented environment.

Mountains generally represent a fragile ecosystem and are highly vulnerable to human impacts. After Communism, the countries in Central and Eastern Europe are entering a period of radical economic and social change that will have enormous impacts, specifically on the natural resource use in the region. There is the transition from the political centralised and controlled system to a free market economy, the development of the civil society and increasing integration with Western Europe and accession to the European Union. For approximately 18 million people this will bring major changes.

Despite many efforts during the past, the high biodiversity of the Carpathians is increasingly threatened by habitat fragmentation or destruction, industrial or accidental pollution, over-harvesting, land restitution, deforestation, intensification of agriculture, new developments in tourism and transport, and inappropriate management methods, as well as increased poverty due to drastic economic changes since transition. While the *accession* of some Carpathian countries to the European Union is welcome, there are concerns that certain EU policies and projects may actually worsen threats to this region, especially the Common Agricultural Policy and proposed road networks. In addition, the Carpathians' current protected areas system is not sufficient in scale, in connectivity or in management effectiveness to protect the region's biodiversity.

3.3 Large carnivores of Europe

A brief introduction to the challenges of carnivore conservation was given in chapter 1, section 1.3. Here, the three target species of this work will be described, justifying their selection.

The systematic order *Carnivora* includes some 240 species (Nowak 1991), 116 of them are in danger of extinction (IUCN 2002). In Europe, there are currently 34 species of carnivores, many of them with overlapping distributions (Mitchell-Jones *et al.* 1999). Except for the polar bear (*Ursus maritimus*), inhabiting some arctic islands, the three largest European carnivores are the brown bear (*Ursus arctos*), the lynx (*Lynx lynx*) and the wolf (*Canis lupus*). Their large size and role as top predators make them function as umbrella species[1]. This implies that their presence in the wild necessarily requires the presence of large areas of relatively well-preserved natural habitat and a number of species that constitute their staple prey. For this reason, they were chosen as the targets of the present study, with the underlying aim of contributing to the conservation of Europe’s biodiversity.

3.3.1 Brown Bear (Ursus arctos)

The brown bear is the largest of the three carnivores considered. Bears have a large head with short nose, small ears and eyes, short tail and a heavy body covered by a thick brown fur. They walk usually on four feet, using the whole feet plant (i.e., they are plantigrada), but can easily stand on the hind legs. For these reasons, the footprints are characteristics and easily recognizable. The claws on the forefeet are longer than in the hind feet and their sense of vision is very little developed, while the one of smell is the one they rely on when searching for food.

Despite belonging to the order of carnivores, bears are definitively omnivorous. This habit is confirmed by the characteristics of their dentition and digestive system. Bears have large molar teeth that suggest an intensive grinding activity, and their digestive tract is longer than usual for carnivores, probably for allowing the digestion and absorption of vegetal material.

Their annual life cycle usually includes a phase of very low metabolic rate, during which bears hibernate. European brown bears have an exceptionally wide distribution that spans from the Rhodopes Mountains in Greece to the Scandinavian forests. This inevitably causes local bear populations to adapt to the characteristics of the local environment they live in, thus adjusting their life cycle and habits to the natural rhythms of the area (Ferguson and McLoughlin 2000, Swenson *et al.* 2000). Particularly, availability of food seems to be the driving factor for determining the timing and eventual absence of hibernation (Schooley *et al.* 1994). For this reason, in some areas of the southern end of their range, bear may not hibernate (Linnell *et al.* 2000). Generally, though, hibernation starts by late autumn and can last from three to seven months. During hibernation, bears maintain a low metabolic rate and use the fat accumulated during summer and autumn as a resource of energy. In some cases, females give birth during this period.

[1] For a definition of umbrella species refer to section 1.1.3 of chapter 1.

Bear diet has been studied intensively in only few places in Europe. In Scandinavia, analysis of bear scats suggested that the importance of meat items in the diet of bears may be systematically underestimated because of the high digestibility of meat proteins, and thus the scarce remains found in the faeces (Dahle *et al.* 1998). Thus, although bear may not kill large prey systematically and rely largely on insects, berries and masts, meat seems to be preferred, when available (Swenson *et al.* 2000). Insects, particularly bees, ants and wasps are recurrent sources of proteins for bears, and domestic animals are occasionally killed by bears.

The areas usually inhabited by bears are forested landscapes with low human density. Forests that may provide denning sites and escape cover are fundamental for bear presence, but food availability and quality may determine the population density (Swenson *et al.* 2000). Preferred food items may include wild and planted fruits and berries, thus openings nearby forested areas are the best landscape composition for bears. Human disturbance may play a significant role in determining the stable presence of bears, particularly when females with cubs are disturbed in the den, they may abandon the site leaving the cubs (Linnell *et al.* 2000).

Hibernating dens are usually natural cavities under rocks or dug into the ground. In some southern populations not all individuals have been reported to hibernate, possibly because food availability is constant all year round (Clevenger *et al.* 1992, Huber and Roth 1996).

Bears are solitary and polygamous. Very little behavioural information is available on European bears as only a few telemetry studies are ongoing in Croatia (Huber D. *pers. comm*.) and Romania (Mertens A. *pers. comm*.). During the mating season, from mid-May to late July, males may mate with several females and each female may mate with different males. Multiple paternity in litters has been documented (Swenson *et al.* 2000). A female can give birth to 1-4 helpless cubs, that remain with her until their second spring. Cubs may stay together until sexual maturity is reached at 4-6 years of age. Female bears may become aggressive if they feel threatened while staying with their cubs.

The home range size of brown bear may depend on resource availability and diverging estimates are available for different sites. In evergreen forests of Scandinavia (characterised by low hard mast production) home ranges may be up to 10 times larger than those in Croatia (where broad leaved forests, Mediterranean climate and artificial feeding sites offer high and stable food availability). Home ranges of male bears have been estimated to have sizes of

1,600 and 128 km^2 in Sweden and Croatia respectively. Females have home ranges of 225 and 58 km^2 in the same countries (Swenson *et al.* 2000).

The distribution of brown bear in Europe has been reduced over the last century. Bears originally occurred throughout most of Europe, but the increase of human population, and the decrease of forested areas and their fragmentation, as well as direct killing, has fragmented the population so that it is now restricted to just a few areas (Fig. 3.3).

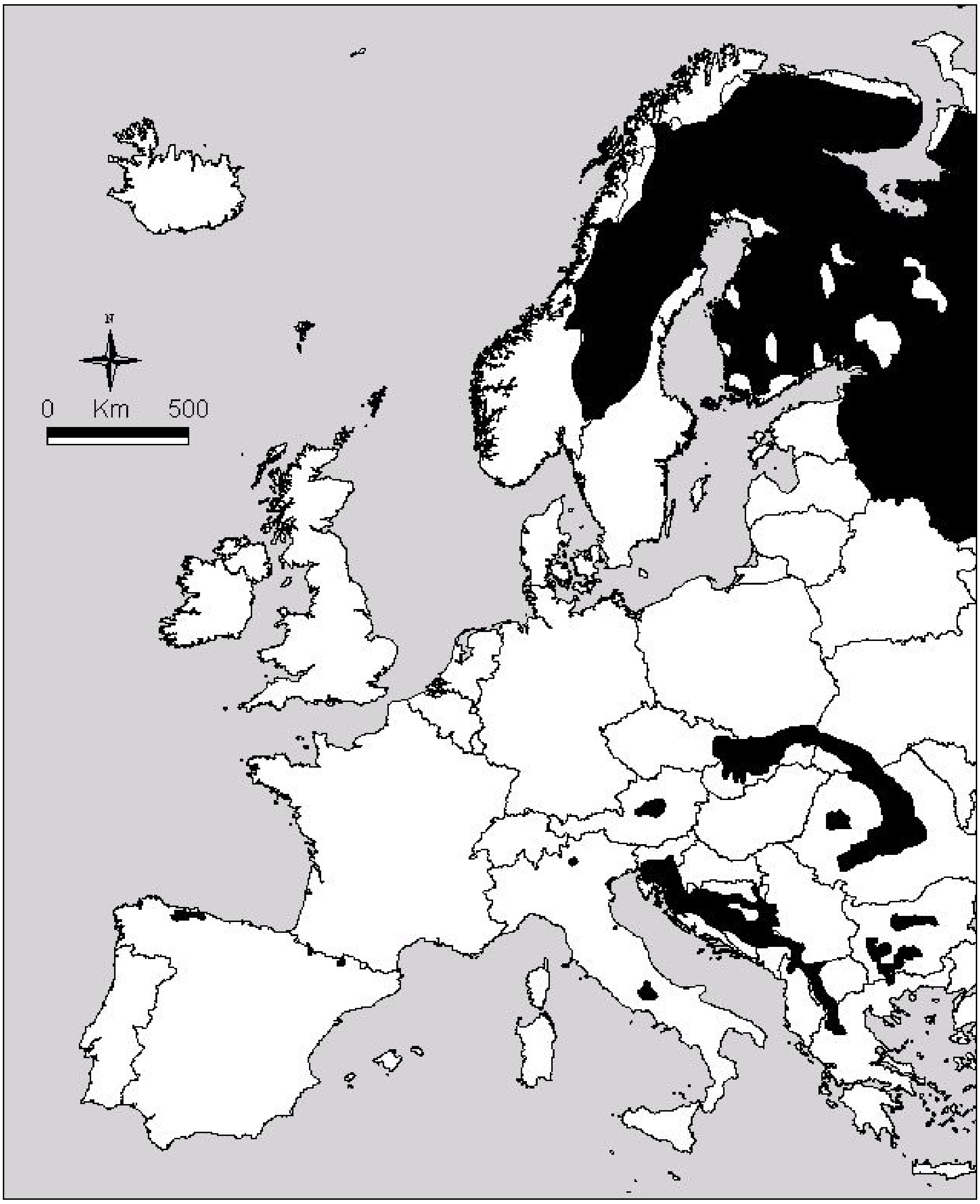


Figure 3.3 – The distribution of brown bear (Ursus arctos) in Europe. Modified from Swenson et al. 2000.

The main European population is represented by the Scandinavian one, in direct contact with the Russian one. In Western Europe, only isolated small populations exist in the Cantabrian Mountains (Spain), the Pyrenees, the Slovenian-Austrian Alps and Italy (few individuals in the Abruzzi National Park in Central Apennines and a reintroduced nucleus in the Alps), the Dinaric-Pindos system of Croatia, Bosnia-Herzegovina and Yugoslav Federation, the Rhodopes Mountains of Greece, the Balkan mountains in Bulgaria, and the Carpathians of Romania, Ukraine, Slovakia and Poland.

The European population of brown bear is estimated to be around 50,000 (of which only 14,000 are outside the Russian Federation). Their densities vary and seem to depend on food availability (Swenson *et al.* 2000). At the extremes are Romania, with the highest density, and Fennoscandia with the lowest density.

3.3.2 European Lynx (Lynx lynx)

The lynx is the smallest of the three species considered, and has some characteristic features that distinguish it from other medium-sized cats. The body is short with short legs, but large furry paws that are an adaptation for moving in winter snow (Nowak 1991). The tail is noticeably short, black tipped, and the cheeks have fur that forms a ruff around the neck. The small triangular ears are tipped by tufts of black hairs. Lynx walk on their fingers (i.e., are digitigrada) and their claws are retractile; used for marking its territory or catching prey, they are extremely sharp. The footprints are clearly visible on snow and easily recognisible for the absence of claws. Sexual dimorphism is pronounced, with males weighing up to twice the females.

Lynx are carnivores that feed mostly on medium-sized animal prey. Ungulates are the staple prey, and preference has been detected towards roe deer (*Capreolus capreolus*), chamois (*Rupicapra* sp.), reindeer (*Rangifer tarandus*) and young red deer (*Cervus elaphus*) in Europe (Birkeland and Myrberget 1980, Breitenmoser and Haller 1993, Okarma 1984, Pedersen *et al.* 1999). Diet varies seasonally and according to availability of food resources, such that in some areas small rodents and rabbits may be the staple prey. Lynx occasionally prey upon domestic animals, mostly sheep, and mainly in areas where local extinction of large predators has occurred at least once in the past (Ciucci and Boitani 1998, Stahl *et al.* 2002), because husbandry practices may have become incompatible with wildlife survival (Breitenmoser *et al.* 2000, Linnell *et al.*1996).

Areas usually inhabited by lynx in Europe are most often large forested landscapes with good populations of adequate prey. Intensive land use may be present in lynx range, as long as the forest areas are connected (Schadt *et al.* 2002). Human disturbance may affect the stable presence of lynx through direct killing. In fact, lynx have long been persecuted by humans because of their reputation of ferocious killer. Nevertheless, in areas where other carnivore predators exist, lynx are reported to affect domestic livestock the least. They might come into conflict with hunters for their dependency on wild ungulate prey, and their lack of scavenging habits (Breitenmoser *et al.* 2000).

Lynx are solitary and monogamous and pairs are formed during mating season. Litter size is often of 1-3 kittens, that stay with their mother up to the age of 10 months. The elusive character of lynx makes them very difficult to study and the few local telemetry studies in Europe are mostly located in Switzerland, France (where lynx were reintroduced in the 1970s), Scandinavia, Poland and Romania.

The home range size of lynx varies according to prey density and landscape characteristics. Little seasonal variation is present, mainly due to the female's lactating period. Estimates range from 180 to 2,780 km^2 for males and from 98 to 760 km^2 for females (Breitenmoser *et al.* 2000). The current distribution of European lynx population is fragmented (Fig. 3.4) and the strongholds are Scandinavia and the Carpathian Mts. Lynx also occur in the Baltic region, the Balkans, the Dinaric and the Bohemian-Bavarian areas, but the status is poorly known.

The distribution of lynx included most of the Eurasian forested areas until the last century. By 1800, lynx had disappeared from nearly all the lowlands and survived in the large mountainous systems, still forming a continuous population throughout Europe. In the mid 20th century, the European lynx population reached its minimum, becoming extinct from most of its original range, and healthy population still survived only in the Balkans and the Carpathian Mountains (Breitenmoser *et al.* 2000). The main cause for this drastic reduction can assumed to be habitat loss and persecution, both caused by human activities. The northern population of Scandinavia has recovered since the 1950s following legal protection, and lynx were reintroduced in the Alps in the 1970s. In this area, conflicts with human activities can sometimes be very strong (Breitenmoser and Haller 1993). The European population of lynx is estimated to be around 7,000 individuals (Breitenmoser *et al.* 2000). Estimates may be subject to bias and errors due to non-uniform data collection methods, and the extreme difficulty to see the animal, as it is mainly nocturnal.

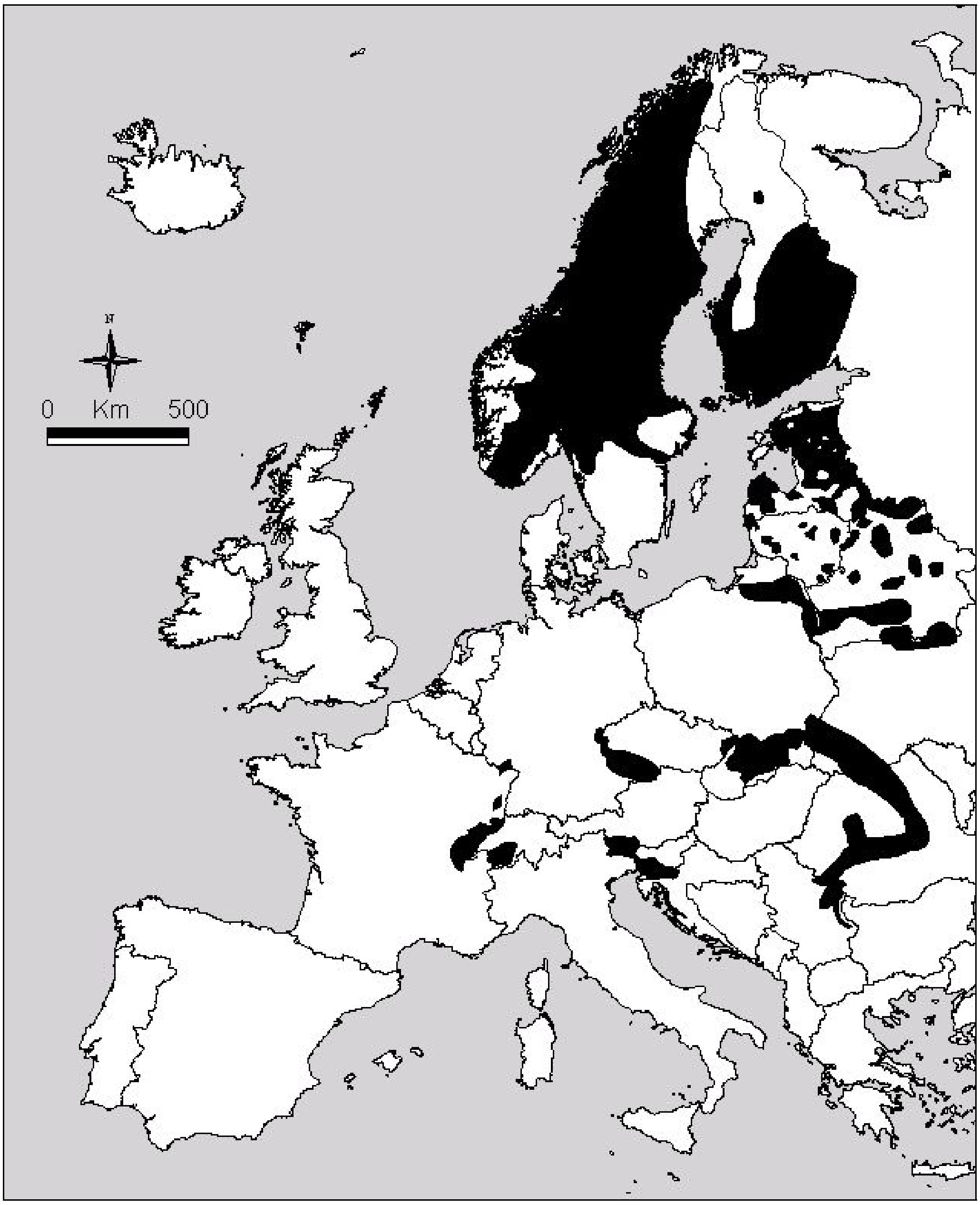


Figure 3.4 – The distribution of lynx (Lynx lynx) in Europe. Modified from Breitenmoser et al. 2000.

3.3.3 Grey Wolf (Canis lupus)

The wolf is the second largest European predator, after the bear. It has the greatest natural range of any living terrestrial mammal (after human beings), and inhabits nearly all the biomes of the Northern Hemisphere, except for tropical forests and arid deserts (Nowak 1991). Such a large range inevitably brings about a great variability that has produced many subspecies, at least 6 of them in the Eurasian continent (Boitani 2000).

Adult males weigh between 20 and 80 Kg on average, the range following a south-north direction, where the smaller individuals are found in the Mediterranean areas and the largest in the Northern regions of Europe. Wolves walk on their toes (i.e., they are digitigrada) and have short nails that always touch the ground, leaving a characteristic mark on their tracks. The tail is usually one third of the body length and it is an important means of communication between individuals.

Wolves feed on a great variety of items. Being strong generalists, they prey on what is available in the areas they inhabit. Their diet may include large prey such as reindeer, deer and wild boar (*Sus scrofa*), as well as rabbits, invertebrates, vegetables and carcasses (Glowacinski and Profus 1997, Smietana and Klimek 1993, Okarma 1991, Boitani 2000). Not least domestic livestock are killed for food, particularly sheep (Ciucci and Boitani 1998, Linnell *et al*. 1996, Mertens and Promberger 2001). Their impact on wild ungulate populations has been investigated over many years, mainly in United States, and it is not very clear (Linnell *et al.* 1999, Mech 1974, Mech and Karns 1977).

Wolves live in packs of variable size, depending on the areas in which they live. A pack is generally a family unit that originates from a mating pair that establishes a territory (Boitani 2000). The relationships between the members of a pack are extremely dynamic, but a very well-established hierarchy dominates them. The result is that individuals at the higher hierarchical ranks usually take the initiative and fight for defending their position or for reaffirming it within the pack. An average pack size is of about seven individuals, depending on the available resources and the hunting pressure suffered.

Generally only one pair mates in each pack, usually the dominant one, the so-called *alpha* pair, but exceptions have been recorded both in Europe and North America (Boitani 2000). An average of six pups per litter are produced after a two month-period of gestation. The newborn remain within the pack for the first two years, after which they either remain in the pack, attempting to reach higher hierarchical stages, or disperse in search of a pair and to establish a new territory. Territories are actively defended by the members of the packs. Individuals of the pack regularly advertise territory boundaries through marking, and trespassing of territory boundaries by alien individuals possibly lead to violent aggression.

Wolves inhabit extremely diverse areas, and their presence has been recorded virtually everywhere that humans do not persecute them. Human disturbance and prey density are the variables that influence their presence the most (Promberger and Schröder 1992, Boitani 2000). In North America, road density has been described as being a critical environmental factor for wolf presence (Mech *et al.* 1988, Mladenoff *et al.* 1995), but this relationship in the diverse landscapes of Europe needs to be considered as a non-linear one, as wolves have been sighted walking along motorways without being affected by them (Blanco, *pers. comm.*).

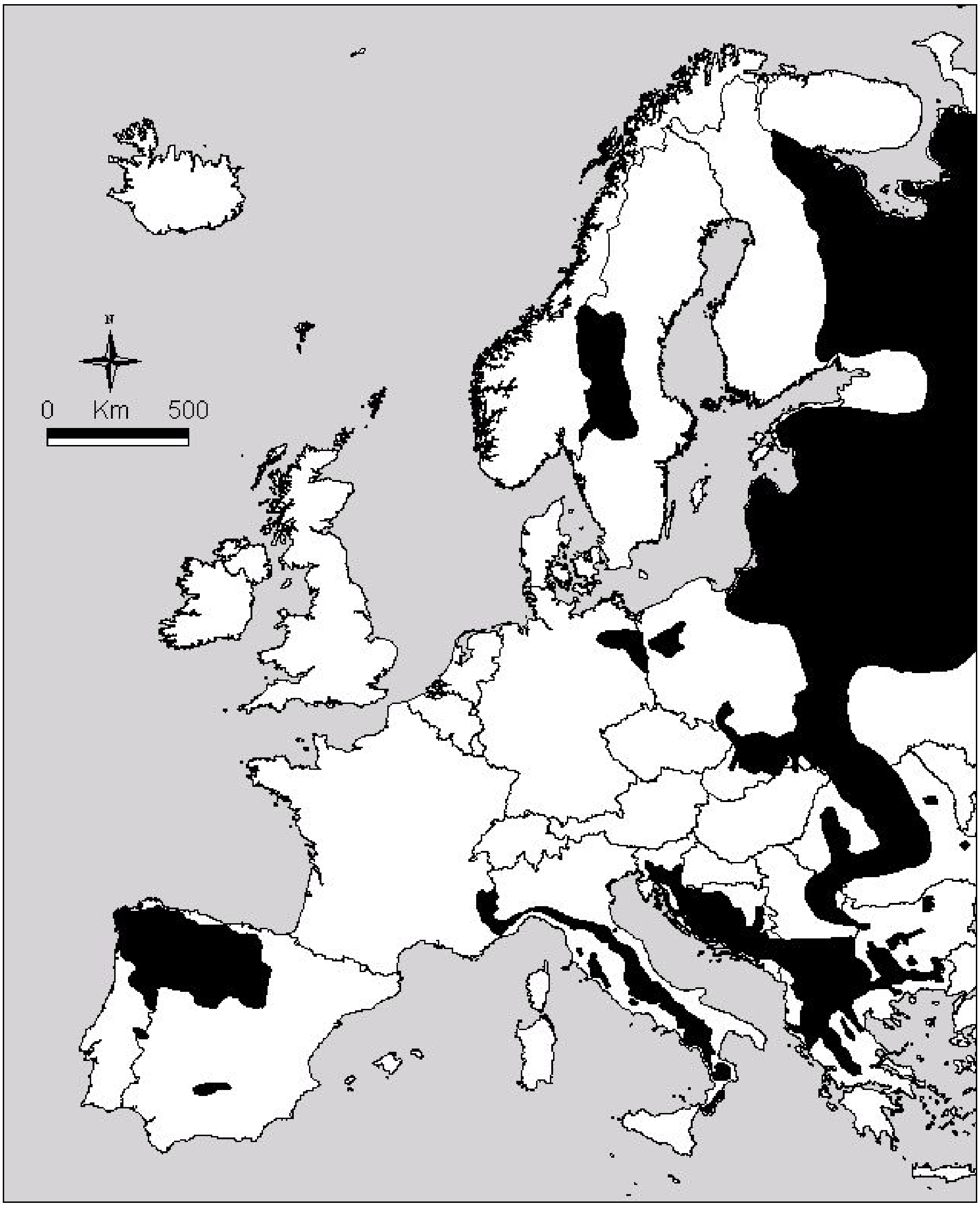


Figure 3.5 – The distribution of wolf in Europe. Modified from Boitani (2000).

Home range size of wolves in Europe is between 100 and 500 km^2 (Boitani 2000) and they coincide with the pack territories. The area within a territory is not used evenly throughout the year, and the space use is regulated by prey distribution and reproductive activities of the pack. The actual distribution of wolves in Europe is sketched in fig. 3.5. This is the result of a dynamic process of decrease and increase of the wolf population.

After World War II, wolves were persecuted throughout Europe and disappeared from central and northern countries. In the 1970s, various campaigns for the protection of wolf started in Europe and the actual population is now expanding naturally as a consequence of wolf adaptation to fragmented habitat, the development of wildlife protection regulations, the changing of human attitudes and the enforcement of international legislation on wildlife conservation.

The European wolf population is now estimated to be around 15,000 individuals, their densities varying according to prey availability and human disturbance. The legal status of wolf varies across countries, according to the population estimates for the country and the intensity of conflicts there exist with human activities.

3.4 Large Carnivores in the Carpathians

Almost half of the Carpathian landscape is covered by forest, the rest being mainly grassland and alpine meadows. These mountains are Europe's last region (outside Russia) to support the largest populations of Brown bears, wolves, lynx, and European bison. Approximately 30 per cent of Europe's wolf populations — a species that has been exterminated in nearly all Western and Central European countries can be found here.

On a continent where 40 per cent of mammals are under threat of extinction, the region is extremely important as an area for refuges and migration corridors for these large mammals, and it offers one of the last opportunities for re-populating large carnivores throughout Europe. Furthermore, these mountains are home to many endemic plant species that are found nowhere else in the world and many threatened and endangered species can be found there. Crucially, the Carpathians form the bridge between Europe's forests in the north and those in the south and west, building a vital corridor for dispersal and interaction of plants and animals, and are probably the only corridor for genetic exchange for its wolf population. The Carpathian population of large carnivores (LC) is the largest in Europe, despite the fact that the Carpathian Ecoregion covers an area not larger than 1% of Europe. The Carpathian bear, lynx and wolf populations represent around 14%, 35% and 30% of European populations, respectively (estimates calculated from data in: Boitani 2000, Breitenmoser *et al.* 2000, Swenson *et al.* 2000). These estimates include European Russia.

The current legal status of the three species of carnivores in the Carpathian countries is reported in Table 3.1, together with estimated population sizes for Poland and Ukraine (in 1999) and Slovakia and Romania (in 2000). The official estimates are considered to be inaccurate by most of the local researchers consulted. They consider that the track counting conducted at hunting ground (HG) level fails to take account of animals that range across more than one HG. Thus, there is an error of double-counting and overestimating the real numbers. The numbers reported in Table 3.1 show the estimates provided by HG managers (official estimates) and by local experts (unofficial estimates). The latter have been produced considering biological information (i.e., average home range size) on local populations and direct field experience. Such discrepancy was surprising, but not new for the local people consulted. The yearly estimates of wildlife species is strongly affected by interests of hunting lobby.

The legal conservation status of some large carnivores has been established only very recently. All four countries have signed the Bern Convention, which stimulates the conservation of European large carnivore populations, but effective legislation for the protection of large carnivores has been adapted to local situations (Hell and Finďo 1999, Okarma 1993).

	BEAR			**LYNX**			**WOLF**		
	Number		**Cons**	**Number**		**Cons**	**Number**		**Cons**
Country	**Offic.**	**Unoff.**	**Status**	**Offic.**	**Unoff.**	**Status**	**Offic.**	**Unoff.**	**Status**
Slovakia	1,467	600	PP	1,037	200	SP	1,281	300	PP
Poland	100	100	SP	250	150	SP	450	250	SP
Ukraine	400	300	P	300	300	SP	400	300	NP
Romania	5,800	5,000	P	2,600	1,700	PP	3,600	3,000	P

Table 3.1 – The estimated number and conservation status (Cons Status) of large carnivores in the Carpathians. SP = Strictly Protected, hunting not allowed at any time of year; P = Protected, with special permits being issued for cases of 'problem animals'; PP = Partially Protected, with hunting restricted to specified periods of the year; NP = Not Protected, hunting permitted all year round. The

estimates reported are official (Offic.) as given by the managers of HG and unofficial (Unoffic.) as modified by local experts. From Salvatori et al. 2002.

The species are strictly protected only in some countries, where compensation for damages they cause is offered by conservation agencies. Compensation is paid in Poland for any proven damage caused by any of the three carnivores, while in Slovakia it is offered only for damages caused by bear to domestic livestock and beehives, and not to agricultural crops or fruits. No compensation is offered in Ukraine or Romania.

This situation calls for a pro-active approach aimed at the maintenance of such healthy populations of LC, as the threats they are exposed to will inevitably lead to a significant reduction in their numbers. The present project was developed with the view of creating a starting point that would help to maximise the conservation efforts at local scales, taking into consideration the broad scale of the Carpathian unit. Although the distribution of the three carnivores in the Carpathians is sketched in figures 3.3, 3.4 and 3.5, they depict only a coarse representation of the reality. Hierarchically, the maps taken from the action plans for the conservation of the three species are extremely useful when the pan-European population is considered. A focus on the single patches of the carnivore populations would highlight the importance to zoom in and consider the Carpathians as a unit. Most importantly, the sketches are only representing the distribution of the three species, without providing any information on the internal structure of the area of occupancy (AO), or where actually within it the species really occur (i.e. their extent of occurrence (EO), see section 2.2.1 for a discussion on the difference and the conservation value of these two concepts).

The following chapter will give an account of the technical approach adopted and details on the methodology used in the present project, aims at estimating the extent of occurrence of the three carnivores within the Carpathian Mountains.

4. DATA SELECTION AND PRE-PROCESSING

4.1 Introduction

One of the outstanding characteristics of the present project is that the object of study is an environmental phenomenon, the presence of large carnivores, that is distributed over a large area regardless of national boundaries. The Carpathians are considered as a geographic and ecological unit, in recognition of the fact that the conservation of large carnivores is a trans-national problem. This was done under the consideration that studying the Carpathians as a unit implies a considerable effort for gathering data from different countries and consequently making them compatible with each other. The geographic database for the four countries sharing the Carpathians represented the basis upon which the classification procedure of environmental quality for the conservation of the three carnivores was developed. The international distribution of a natural variable (in this case wildlife species' presence) made the first phase of the data processing lengthy and tedious.

In this chapter, the preparation of the maps of environmental variables will be described. Section 4.2 will describe the variables selected for environmental classification. Environmental variables were not always available in an explicit geographical format, and sometimes proxies or indices were identified. The data representing the selected variables will be described, together with an account of the sources that provided them. Furthermore, the various steps taken to produce a uniform data set that could be then used for the core classification phase will be introduced in section 4.3.

The present chapter is thus designed to provide background information about the methods used to prepare the data for the classification process. The latter will be introduced in chapter 5, together with the presentation and discussion of the results obtained.

4.2 Environmental Variables

The presence of large carnivores is highly dependent on land cover, as forested areas are certainly one of the determining factors (see section 3.2 of chapter 3) regulating their spatial distribution. The other important factors seem to be the availability of food and human disturbance (Boitani 2000, Breitenmoser *et al.* 2000, Swenson *et al.* 2000). In light of the characteristics of the life cycle of the three target species that are strongly regulated by the presence of three factors mentioned above, the first-phase selection of environmental variables saw an exploratory procedure driven by biological knowledge.

The type of vegetation present on the territory represents an extremely important variable for wildlife in general. It is an index of many other variables (such as food production, shelter availability, etc.) that are critical for large carnivore presence. Forested areas provide masts (seeds and fruits) for bears and shelter for the three carnivore species. They also represent a food source for ungulate prey of wolf and lynx. Taking account of the cultural traditions that aim at conserving forests in mature but productive state and the natural heritage present in the countries considered, it is assumed that virtually all the forested areas in the Carpathians are inhabited by ungulate species such as roe deer, red deer, wild boar, chamois and hare, their relative distribution being regulated by micro-factors such as understorey vegetation and rocky terrain. This assumption may not hold true in other parts of Europe, where the ungulate populations are present at very low densities or absent mostly due to intensive hunting activities. In the Carpathians, though, the populations of ungulates are managed by hunters and foresters with the main aim of maintaining a constant harvest portion of the populations (Salvatori *et al.* 2002) for the next hunting season. Under such an assumption, vegetation type could be a proxy for food and shelter availability.

Given that the study area is a mountainous region, altitude was thought to be a relevant environmental variable to include in the analyses. An exploratory analysis using point locations of each species' presence against altitude showed that there was an altitudinal range within which the three species were present. Particularly, bear presence was included in areas between 296 and 1,849 meters, lynx was present in an altitude range of 181-1,627 m, and wolf presence was detected in areas of altitude ranging from 228 and 1,577 meters. Such ranges are indices of a combination of human absence and forest presence, which are usually highly correlated to altitude. Altitude may also represent a proxy for snow presence in mountainous areas. Snow lasts longer at higher altitudes, and may be deeper in areas where terrain is not rough. The terrain roughness may be a significant variable for the presence of wildlife: it represents a barrier to suitable habitats for some species and it can provide shelter in other cases. This variable was not used here because of the relatively simple inputs that the study required for model development. The whole procedure of variable preparation aimed at manipulating the raw variables as little as possible, in order to maintain the most direct control on the input data. Thus, the altitude data were used in the form of a digital elevation model, expressed as continuous values.

The other variable that was considered to have a strong impact in determining the environmental suitability for large carnivores was the presence of human disturbance. This is mainly driven by the fact that the species have been persecuted by humans for decades and are continuing to be so in most of their distribution range. Although hunting of bears, lynx and wolf is regulated in the Carpathians (Salvatori *et al.* 2002), illegal killing is widespread and the economic changes that the Carpathian countries are about to undergo do represent a threat to the survival of these species, mainly due to the encroaching of human activities into natural ecosystems.

The following variables were selected as input for the environmental suitability classification:

- Vegetation type
- Altitude
- Human disturbance

Vegetation type was expressed in the form of land cover classes coming from a European land cover map (CORINE). Such a database was thought to be ideal in terms of consistency of classes across most of the countries considered. A description of the database will be given below. Each class of the land cover map acquired was transformed to a binary variable expressed as either presence or absence. The steps involved in such a process are described in section 4.3.

Altitude data were sought at national level after a negotiation process with a Russian consultancy to supply data for the entire Carpathian region failed to reach an agreement mainly due to the lack of clarity in citing the source data.

Not all the selected variables were explicitly represented in spatial data layers. In particular, the variable of human disturbance, difficult to find in spatial format, needed to be represented by indices of presence, such as human settlements and roads, that were available in spatial format. Although human population density in the form of a continuous data layer could have proven useful, the population data were only available at provincial level, and at a spatial resolution not suitable for the analyses carried out here. Thus it was assumed that all urban centres had constant human density, which equates to potential human disturbance. Also, asphalted roads permitting vehicle transit at a speed that represented a threat to wildlife were equated to human disturbance. These indices of human disturbance were binary variables expressed as presence/absence.

Once the contacts were established, negotiations were started to gather the data needed for environmental classification. Table 4.1 lists the spatial scales at which the geographical data were available for each country.

	ROMANIA	SLOVAKIA	POLAND	UKRAINE
LAND COVER	250m	250m	250m	1:200,000
RIVERS	1:100,000	1:50,000	1:50,000	1:200,000
LAKES	1:100,000	1:50,000	1:50,000	1:200,000
SETTLEMENTS	1:100,000	1:50,000	1:50,000	1:200,000
RAILROADS	1:100,000	1:50,000	1:50,000	1:200,000
ROADS	1:100,000	1:50,000	1:100,000	1:200,000
ELEVATION	1:50,000	1:50,000	n.a.	1:200,000
Large Carnivore LOCATIONS	1:200,000	coordinates	1:250,000	1:1,000,000

Table 4.1 – The data were received at different scales and spatial resolutions for the four Carpathian countries.

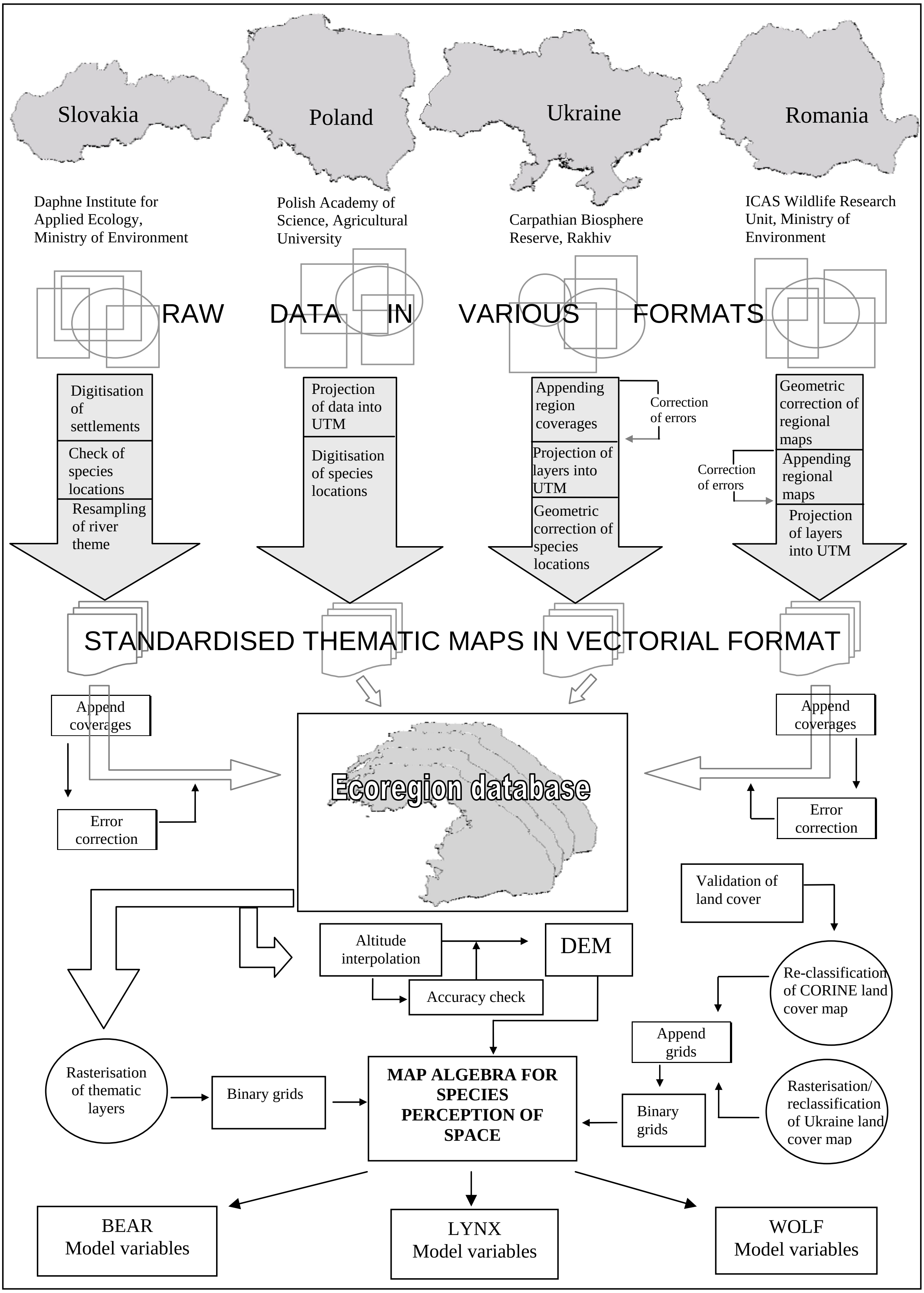
The final aim of the pre-processing phase was to have a set of digital layers, each one representing a variable (either continuous or binary) that could be used as an input for the environmental classification phase. In order to achieve this, the layers from different countries needed to be standardised both in terms of their geographical characteristics (i.e. coordinate system and spatial scales) and the information they carried (i.e. feature attribute tables, FAT).

4.3 Data pre-processing

A number of steps needed to be considered when using data generated from such diverse sources. Very often the data obtained were incompatible with each other in format, and therefore unsuitable for any statistical analysis in their raw form.

The diagram in figure 4.1 sketches the various steps of the pre-processing phase. The whole flow took more than two years of work, at the end of which the data were finally in the appropriate format for being classified to produce environmental suitability maps for the three carnivores.

Figure 4.1 – The main pre-processing steps from raw data to variables ready to be used in the modelling procedure.



4.3.1 Land Cover

The environmental variables were acquired in digital map format from diverse sources, most frequently local Environmental Systems Research Institute (ESRI) dealers, at different available scales and co-ordinate systems. A land cover map for Europe was acquired from the Swedish Space Corporation Group, Satellus, which has the right to sell the CORINE land cover map. The CORINE land cover map is the product of the COoRdination of INformation on the Environment programme launched in 1985 by the European Union and coordinated by the European Environment Agency (EEA 1995). Activities were expanded to central-eastern European countries in 1992 as part of the PHARE programme.

The CORINE land cover data set was tested in a sample area in the Southern Carpathians, within the Romanian portion of the mountain complex. A subset of a LANDSAT 7 ETM+ satellite image was classified for land cover through an expert-knowledge based approach, whereby the areas characterised by 4 established land cover classes were digitised over the satellite image. In cases of uncertainty, they were visited on the ground. The classes used were:

1. Forest
2. Grasslands
3. Agriculture
4. Urban areas

When comparing the CORINE land cover map with the one produced through digitisation of the Landsat image, some discrepancies were found at classes level, mainly due to the difference in detail and spatial resolution (i.e., 250 m versus 30 m). Thus, the subset of the CORINE data base corresponding to the area covered by the Landsat image was reclassified according to the categories established for the satellite image classification. The comparison between them was encouraging; reaching K-statistics of 0.7. Although the level of coincidence between the two land cover maps may be affected by the low number of classes, these were the most relevant ones within the area considered. A more detailed land cover classification of the Landsat 7 image was performed for other purposes and will be described in chapter 6.

Once the CORINE land cover map was assessed for accuracy and its performance believed to be acceptable for the purpose of the present study, the pre-processing phase followed with the re-classification of the map into a thematic map containing information that was relevant for the large carnivores considered. The steps taken to extract the relevant data from the CORINE land cover map will be described in the following paragraphs.

In order to use the information contained in the land cover maps as input variables for the GIS classifier, a set of specific covers were produced. The CORINE land cover contains 44 cover classes. Of these classes, 36 were present in study area and were then grouped into seven classes (fig. 4.2).

CORINE CLASS	NEW CLASS	ID
Continuous urban fabric		
Discontinuous urban fabric		
Industrial or commercial units		
Port areas		
Airports	Urban Areas	5
Mineral extraction sites		
Dump sites		
Construction sites		
Green urban areas		
Sport and leisure facilities		
Road and rail networks and associated land	Roads	6
Non-irrigated arable land		
Permanently irrigated land		
Rice fields		
Vineyards		
Fruit trees and berry plantations		
Olive groves		
Annual crops associated with permanent crops	Agriculture	3
Complex cultivation patterns		
Land principally occupied by agriculture, with significant areas of natural vegetation		
Sclerophyllous vegetation		
Transitional woodland-scrub		
Agro-forestry areas		
Broad-leaved forest	Forest	1
Coniferous forest		
Mixed forest		
Natural grassland		
Moors and heathland		
Pastures	Grassland	2
Sparsely vegetated areas		
Burnt areas		
Beaches, dunes, sands		
Bare rocks	Barren land	7
Glaciers and perpetual snow		
Inland marshes		
Peat bogs		
Salt marshes		
Salines	Water	4
Intertidal flats		
Watercourses		
Water bodies		
Coastal lagoons	Not present	
Estuaries	Not present	
Sea and Ocean	Not present	

Figure 4.2 – The re-grouping of CORINE land cover classes.

This was done according to the assumption that the presence of large carnivores is related to the presence of forest cover and therefore prey species (see chapter 3), because the prey species are dependent on forests for cover and food. In fact, large carnivores probably do not distinguish between continuous and discontinuous urban fabric, and if they do so, it may be relevant to separate those two classes when analysing the environmental suitability at a finer spatial resolution than the one used here. Furthermore, some of the CORINE land cover classes were highly underrepresented in the Carpathian range. This is the case for categories such as airports, port areas, sport and leisure facilities, peat bogs, and dunes, among others. For these reasons, the land cover classes considered to be of the same environmental nature were grouped together. The reclassification of the land cover maps was performed in the Arc-Info TABLES module.

Figures 4.3 and 4.4 shows the original CORINE and reclassified land cover maps of the study area, respectively. They also show that the CORINE land cover database does not include the Ukrainian territory. The land cover of Ukraine was received from the Carpathian Biosphere Reserve of Rakhiv in vector format as separate polygon layers. They were converted into a raster grid and re-grouped as before in order to convert them into a compatible format with the other data sets. The resulting map for Ukraine is shown in Fig. 4.5.

Figure 4.3 - The raster image of CORINE land cover with the original classes.

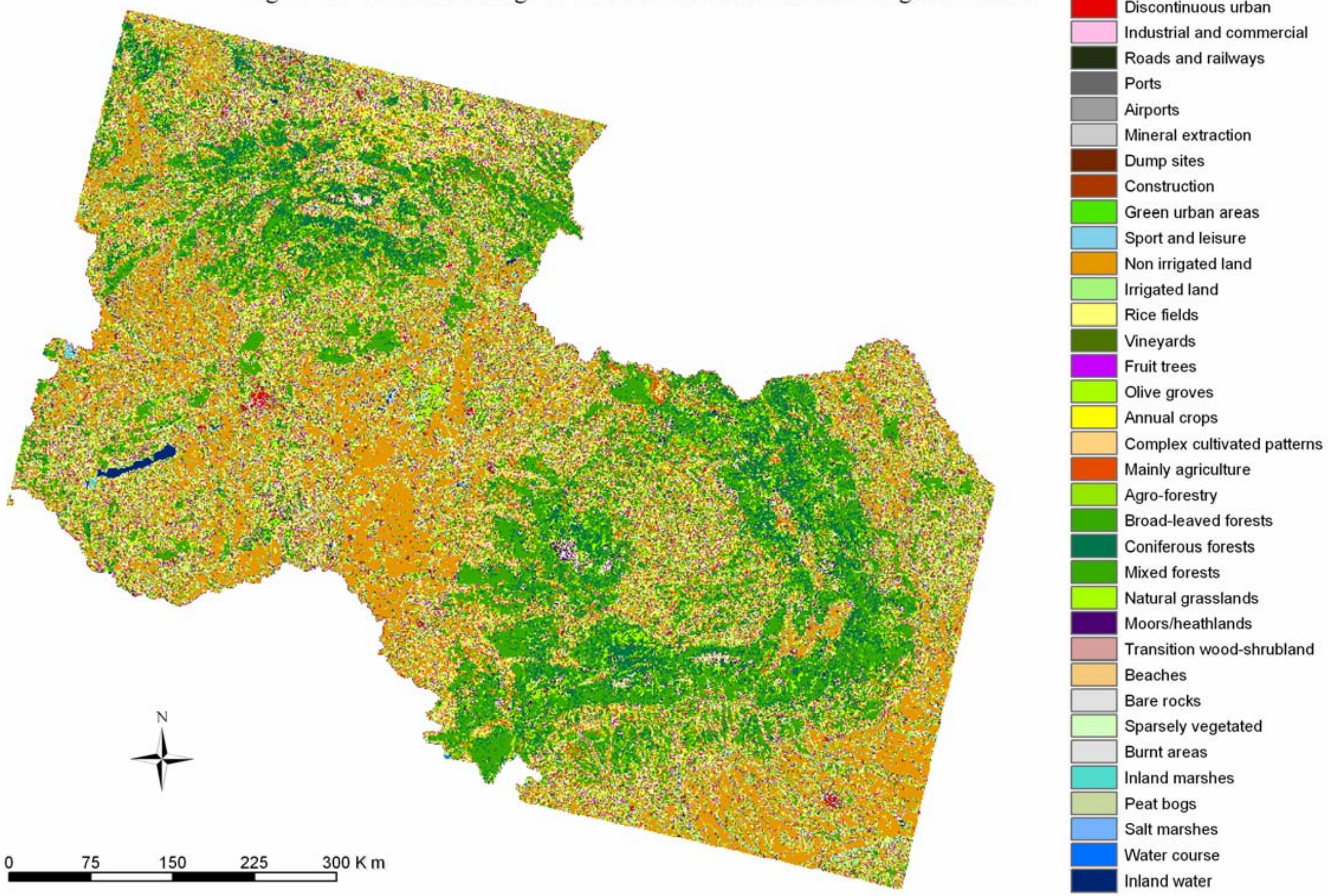
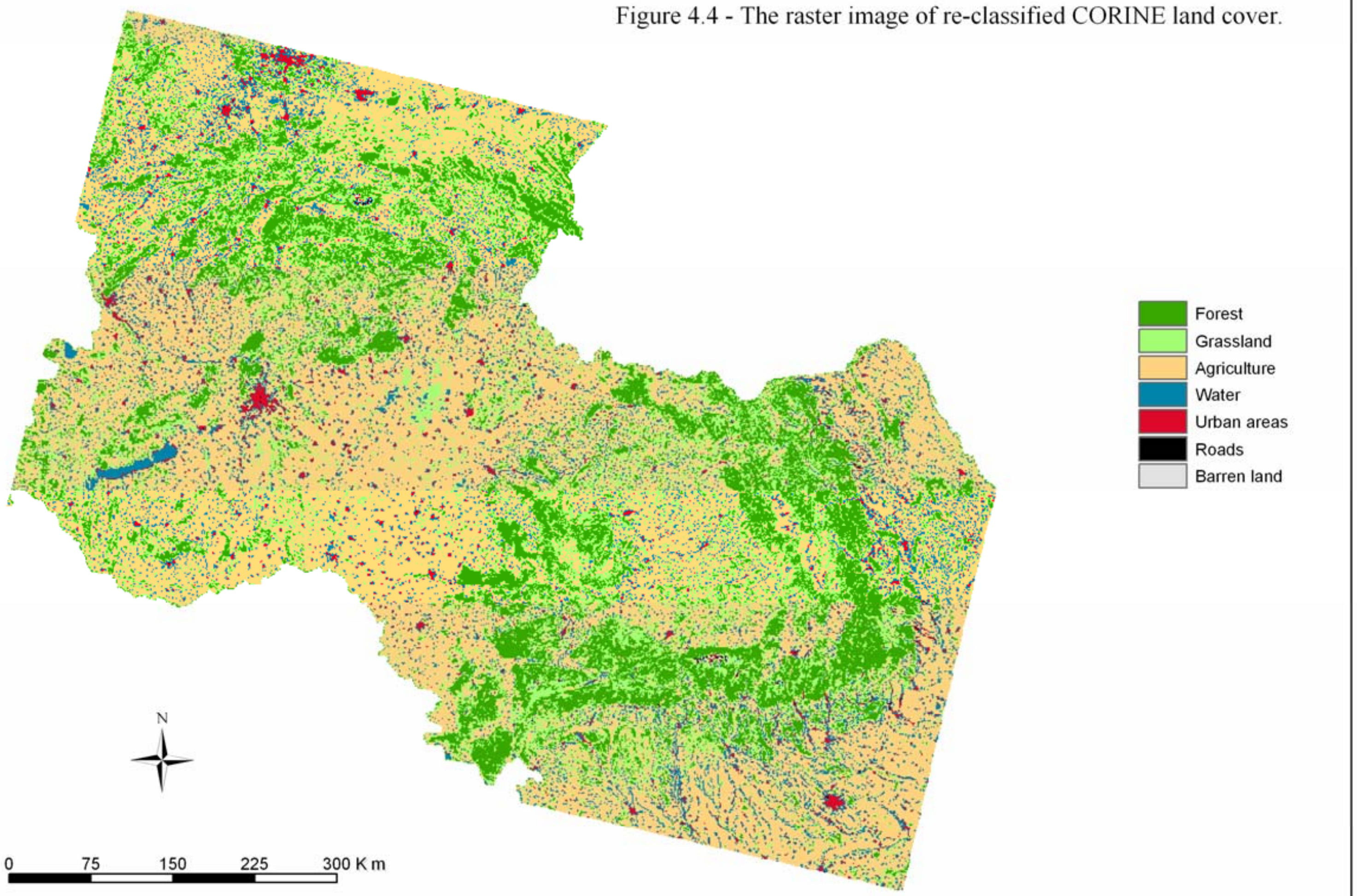


Figure 4.4 - The raster image of re-classified CORINE land cover.



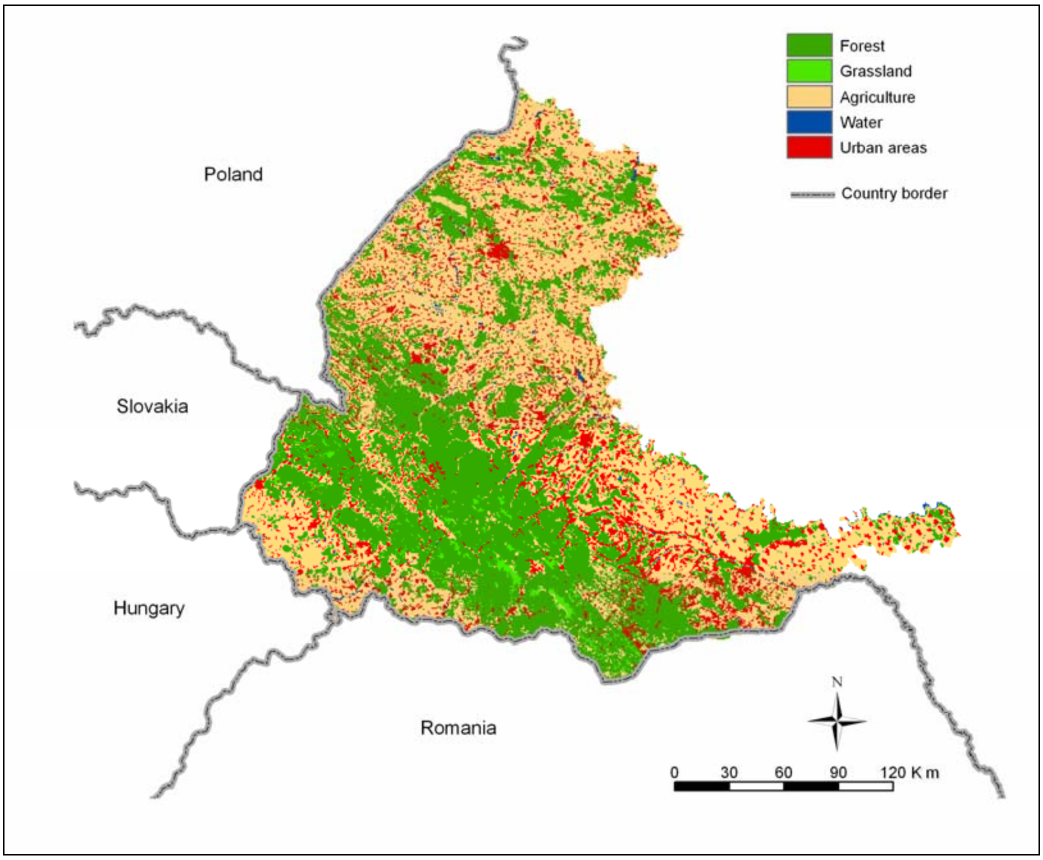


Figure 4.5 – The raster image of land cover of Ukraine. The area represents only the four administrative regions (oblasti) that cover the Carpathian Mountain range: Lvov, Zakarpatzky, Chernov, Ivano-Frankysk.

Finally, the reclassified CORINE land cover and the newly generated land cover image of Ukraine were merged together. Table 4.2 reports the area included in each of the new classes of the map resulting from the unification of CORINE and the map of Ukraine.

The classes were then associated with a unique identification number and separated. In this way, each class was represented by a raster image where the pixels with value corresponding to the one associated to the class considered were given value 1 and the others were given a value 0. Thus seven binary covers (value 0-1) were produced.

Table 4.2 – The area covered by the reclassified cover types and their relative percentages of the whole study area.

Class	Km sq	% of total area
Forested Areas	118,390	29.7
Grassland	38,072	9.6
Agricultural Areas	214,046	53.8
Barren Land	762	0.2
Water Bodies	4,143	1.05
Urban Areas	22,143	5.6
Roads	86	0.02

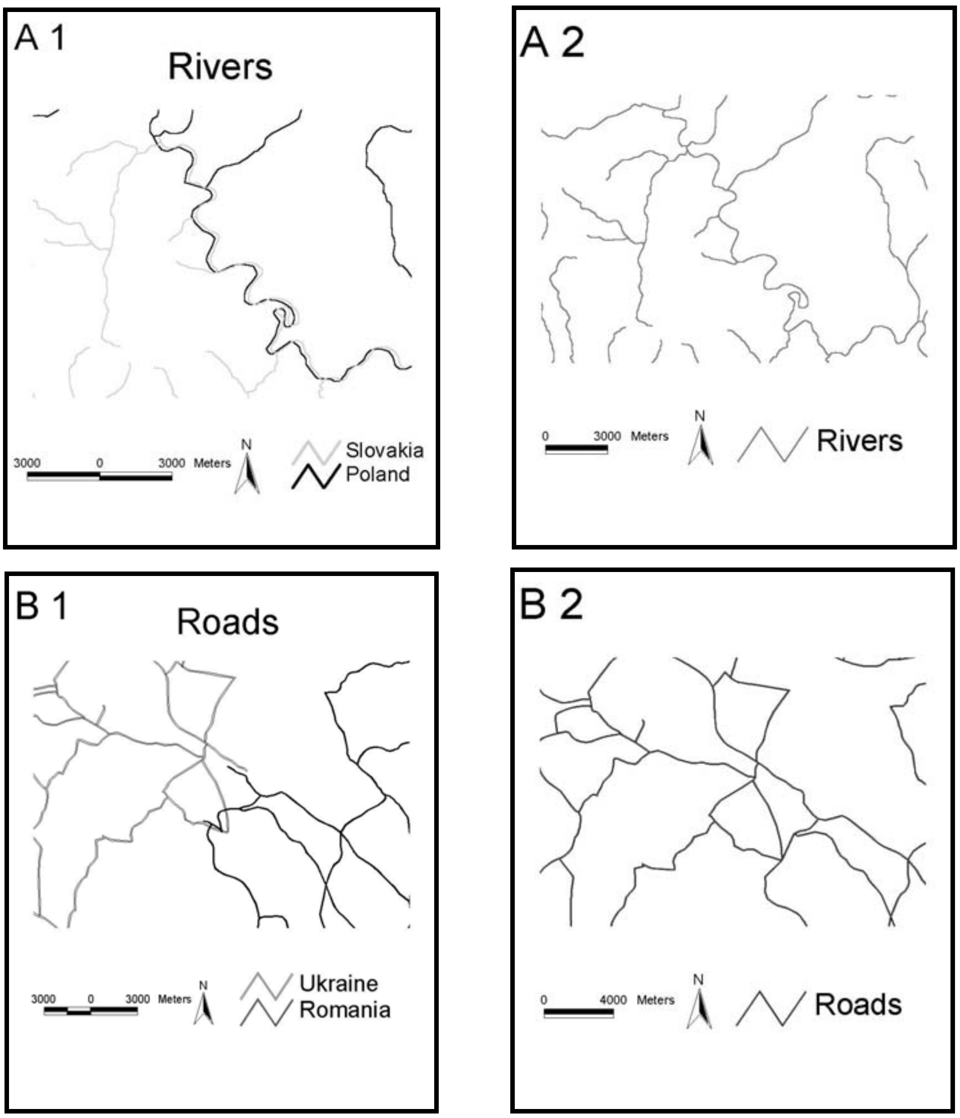
4.3.2 Rivers, lakes, settlements and roads

Together with the land cover data, additional geographical data were acquired for the four countries considered. Once the thematic coverages of the variables considered were available for all the four countries, the first step in the pre-processing of digital maps was the standardisation of coordinate systems to the UTM WGS84 system. This was done using ESRI Arc Info with the routine PROJECT, selecting a nearest neighbour resampling method.

The different layers for Romania were requested and received in the UTM WGS84 coordinate system at the moment of purchase. Data from Ukraine and Slovakia were obtained in Lat/Long and UTM Gauss-Kruger coordinate systems, respectively. Data from Ukraine came separately for the four different administrative regions covering the Carpathian portion of the country. The covers from each thematic layer were appended in order to have a single layer for each variable at country scale. The Agricultural University of Kraków supplied data for Poland in a geographical coordinate system on request.

Once the geographic projections of the thematic covers for each country were transformed into the uniform UTM WGS84, they were appended in order to have a digital map of each variable for the whole Carpathian Ecoregion. The coverages were checked visually at the border areas for identifying those features that needed to be modified before they could be appended. Nevertheless, the resulting maps retained some errors due to lack of coincidence at the boundaries, e.g. roads or rivers crossing the border of two countries, or lines (e.g., rivers) that were repeated at the border of two covers. Sliver polygons resulting from the automatic appending of adjacent covers were eliminated using the DISSOLVE command in Arc Info, while the mismatch of linear features was corrected using paper maps as a reference for adjusting the arcs in one of the two covers considered. Mismatches of less than 100 m were not corrected because the covers had to undergo the process of rasterisation with cell sizes of 250 m. Figure 4.6 shows two examples of errors encountered where covers met: errors due to repetition of line features, and mismatching of line features that are supposed to continue from one nation to the other. In the specific example, the river Poprad that marks the national boundary between Poland and Slovakia is present in both the river coverages coming from the two countries (Fig. 4.6 A).

Figure 4.6 – Example of errors encountered in the pre-processing phase and the resulting corrected coverages. Line feature repetitions, (in this case the Poprad river, A1) and mismatch at the border areas (in this case the road E85 from Suceava in northern Romania to Černivci in southern Ukraine, B1). The errors were corrected editing the single coverages before appending them (A2 and B2).



Other corrections had to be made, such as the digitisation of Slovak settlements. The digital map of Slovak settlements was acquired from the Slovak Environmental Agency (SEA) of the Ministry of the Environment, at an agreed reduced price in exchange for the collaboration in a sub-project on bear conservation in Slovakia. Such an agreement gave the SEA the right to use the coverages bought from a local ESRI dealer. The original geographical scale of the data set was 1:50,000 and it needed to be transformed into UTM coordinates by the SEA. The detail was much too great to be integrated with the other data, and no operations could be made on the cover because the accidental superimposition of polygons representing isolated building blocks would create errors during the building phase (command BUILD in ARC) of the feature attribute table (FAT). The solution was then to re-digitise the whole cover and including several settlements of the original coverage in one polygon. The digitising was done by the author on screen and involved drawing polygons around features that were represented as unique polygons in the road atlas of Slovakia at a scale of 1:150,000. Polygons representing isolated buildings that were scattered and not represented in the road atlas were excluded from the new coverage. Figure 4.7 shows an example of how the original cover and the newly created one look like.

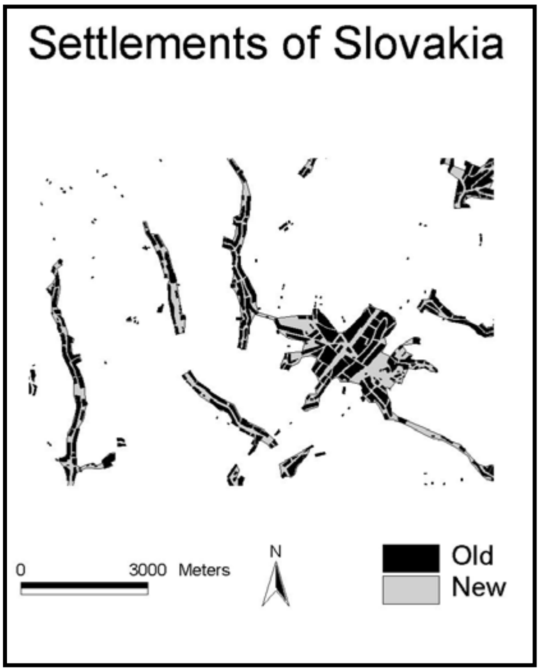


Figure 4.7 – An example of the coverage representing the human settlements of Slovakia. The polygons of the original and the new coverages are represented in black and grey, respectively.

The subsequent steps of data pre-processing included the transformation of vector layers into raster formats suitable for spatial analyses. For practical ease, only one feature attribute was associated to each cell in the output raster images. The FAT of each cover was modified so as to contain a unique ID for each feature. Such ID was the only information retained in the rasterised version of each layer, the remaining information being stored in a relational database with a lookup table (LUT) that contained the same ID as relational field. The raster images for each layer were generated in Arc Info using the cell size and origin reference consistent with the grids of the CORINE land cover at 250m resolution.

4.3.3 Digital Elevation Model (DEM)

Altitude data at a spatial resolution compatible with that of the CORINE land cover was sought for in each country. Isopleths for Slovakia and Romania were purchased from local ESRI dealers at scales of 1:50,000 and 1:200,000, respectively. Those for Ukraine were supplied by the Carpathian Biosphere Reserve at a scale of 1:200,000, while those for Poland were not available. Once the isopleths for the three countries had been standardised in terms of geographical coordinates and matching of lines across national boundaries, a DEM was generated in the ARC module of ARC INFO, using the TOPOGRID command. This command activates an interpolation procedure that uses the information provided by commonly-available data sets such as isopleths (ESRI 1994). The interpolation method is an inverse distance-weighted one, which performs particularly well in areas where distance between isopleths is small, i.e. in non-flat areas (Hutchinson 1993). The boundary and cell size was set to that of the CORINE land cover grid. The raster image of the DEM generated is shown in figure 4.8.

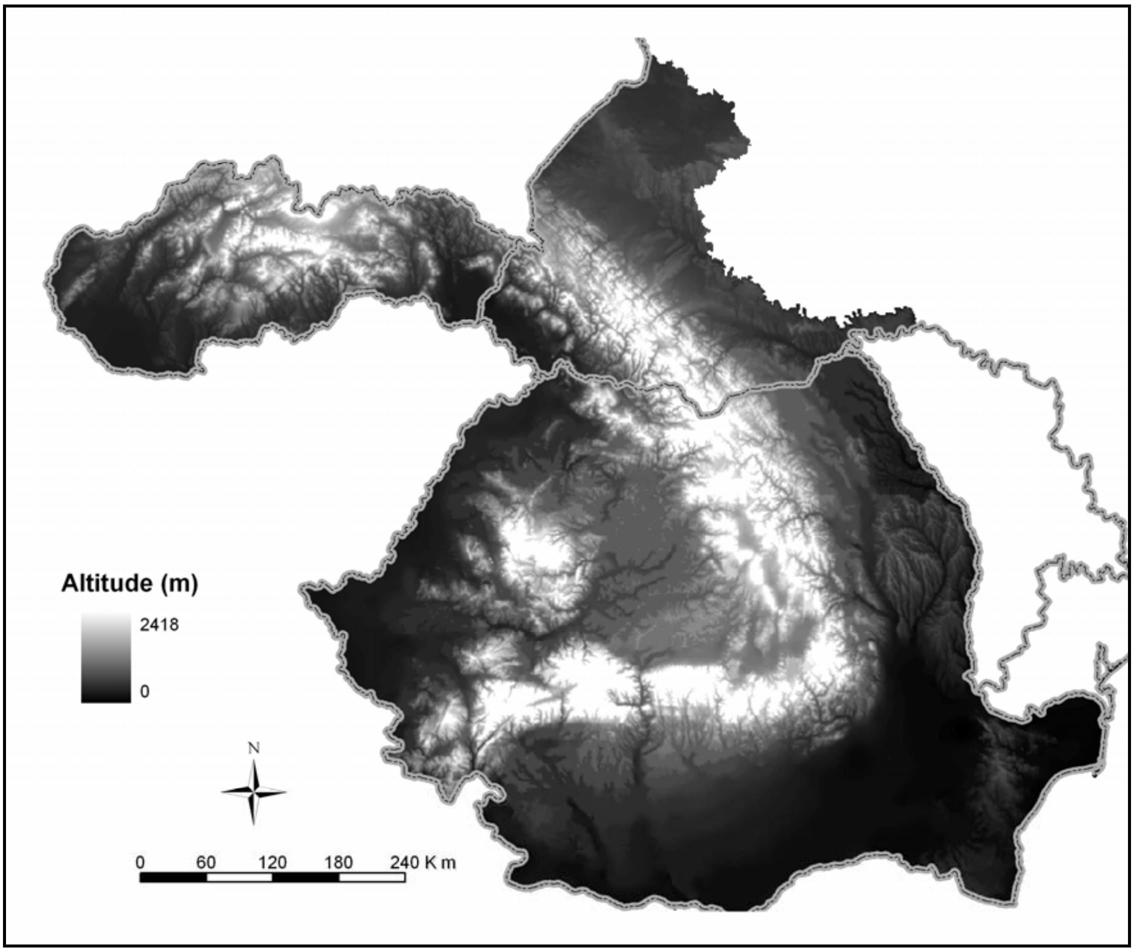


Figure 4.8 – The digital elevation model generated at 250m resolution from the isopleths obtained in the Carpathian countries. Altitude data for Poland were not available.

A visual evaluation of the results was undertaken by generating a new set of contours from the newly-generated DEM and comparing them with the original ones. Although the details of the original isopleths were lost in the newly-generated contours, the overall pattern appeared to be consistent (fig. 4.9), and when building a buffer of 100m around the newly-generated isopleths 53.4% of the original ones where within such distance, while up to 87.7% of them where included in 250m buffer areas.

A visual comparison with the raster image of the DEM downloaded from the United States Geological Survey web site (USGS 1998) was also performed and showed no inconsistencies between the two. Although this kind of accuracy testing is only a rough and general one, particularly because the results to be checked were at a finer spatial resolution than the reference raster, a visual check was considered to be appropriate for the purpose of the study.

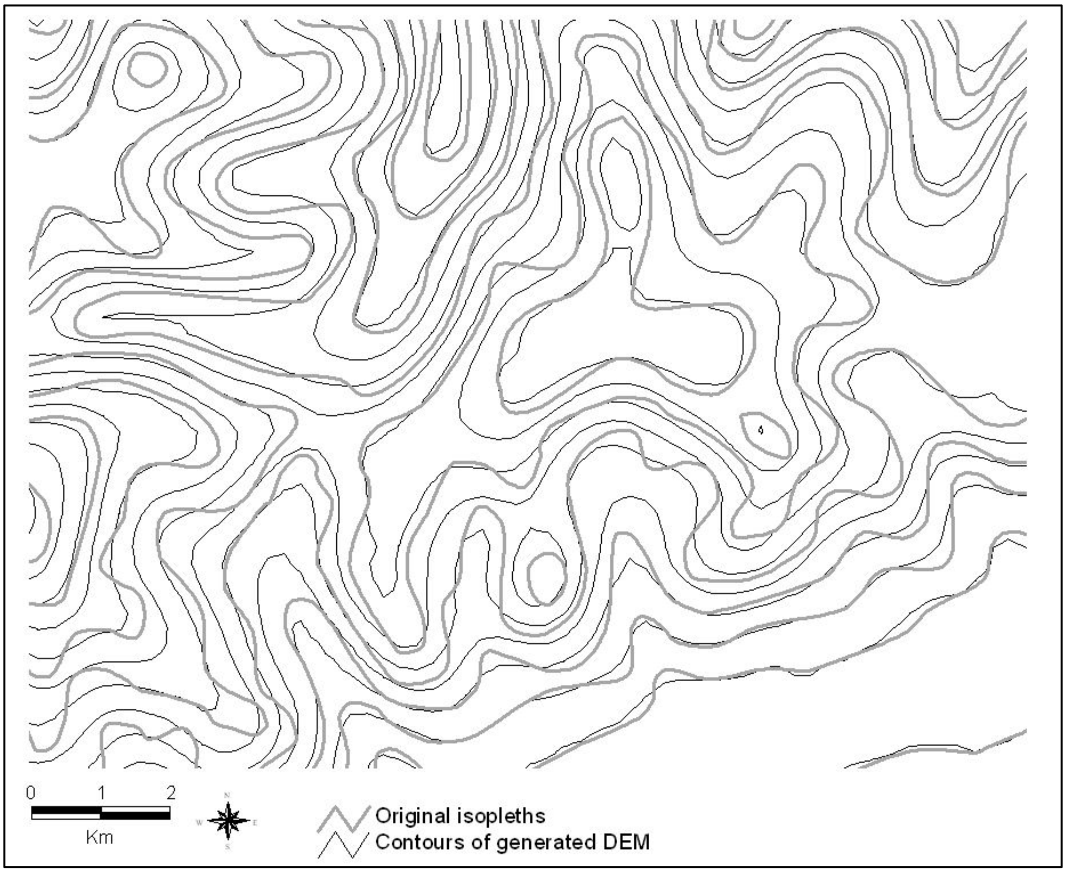


Figure 4.9 – The evaluation of the DEM generated from the contours was performed through comparison between the contours generated from the DEM (black thin line) and the original isopleths (grey thick line).

The lack of altitude data for Poland was a major issue during the first two years of the project, while looking for all the available data on the study area. A negotiation process with Prof. Pawel Brzusky at the Agricultural University of Krakow was started in April 2000 and lead to the acquisition of all layers needed for Poland except the altitude. The only available maps of Poland were topographic maps of the 1940s where altitude contours were barely visible and digitising them proved to be too lengthy and difficult for the scale of the source map (1:50,000). The USGS DEM was at a spatial resolution of 1 km, and using it would have brought all the other layers to such resolution, as the spatial resolution of analyses always coincide with the coarsest resolution of the available data (Dubayah *et al.* 1997). Thus it was decided to run the model over two separate sets of data, one spatially restricted to Poland alone and lacking of the altitude layer, and the other for the rest of the Carpathians, including the DEM generated from the isopleths. This approach would minimise the effect of lack of terrain information over the whole study area, limiting it to the Polish portion of the Carpathians.

4.3.4 Large carnivore locations

The information about where large carnivore are present was obtained from local experts and came in the form of point locations indicated on local maps at various spatial scales. They were digitised to form a point layer in the GIS. Different strategies were followed, depending on the original format of the data.

The locations from Poland were indicated on a tourist map of the Carpathians and were translated into point locations in the digital maps of the area according to their locations with respect to land marks and geographic features such as rivers, roads and settlements.

Those from Ukraine came as point locations sketched on a general map of the Ukrainian Carpathians. As the landmarks in the original map were poor, the map was geometrically corrected using the west- and southernmost national borders and the north- and eastern limits of Ukrainian Carpathians that were marked by the River Deisper. Sketch maps of Ukraine were geometrically corrected using 55 ground control points (GCP) and the mean geographic error was always less than 200 m. Fig. 4.10 shows an example of the original data as obtained by the Ukrainian contributors.

Locations of large carnivores in Slovakia came as a coordinate file and were input as such after a check on consistency between coordinate and actual location. This was done by submitting a map containing the point locations to the person who actually provided the coordinates, in order to assess whether the points were placed in the correct location.

Romanian locations of large carnivores were originally obtained as point locations on forestry maps of Romanian regions that were obtained as scanned images without geographic coordinates. Large carnivore locations were provided by local foresters and hunters who had directly seen the animals or their tracks. Twenty-seven Romanian regions are included in the Carpathians and each map was geometrically corrected using vector layers of roads, railroads and rivers. An average of 50 (±20 SD) ground control points were used to ensure that the geographic error was always less than 200m.

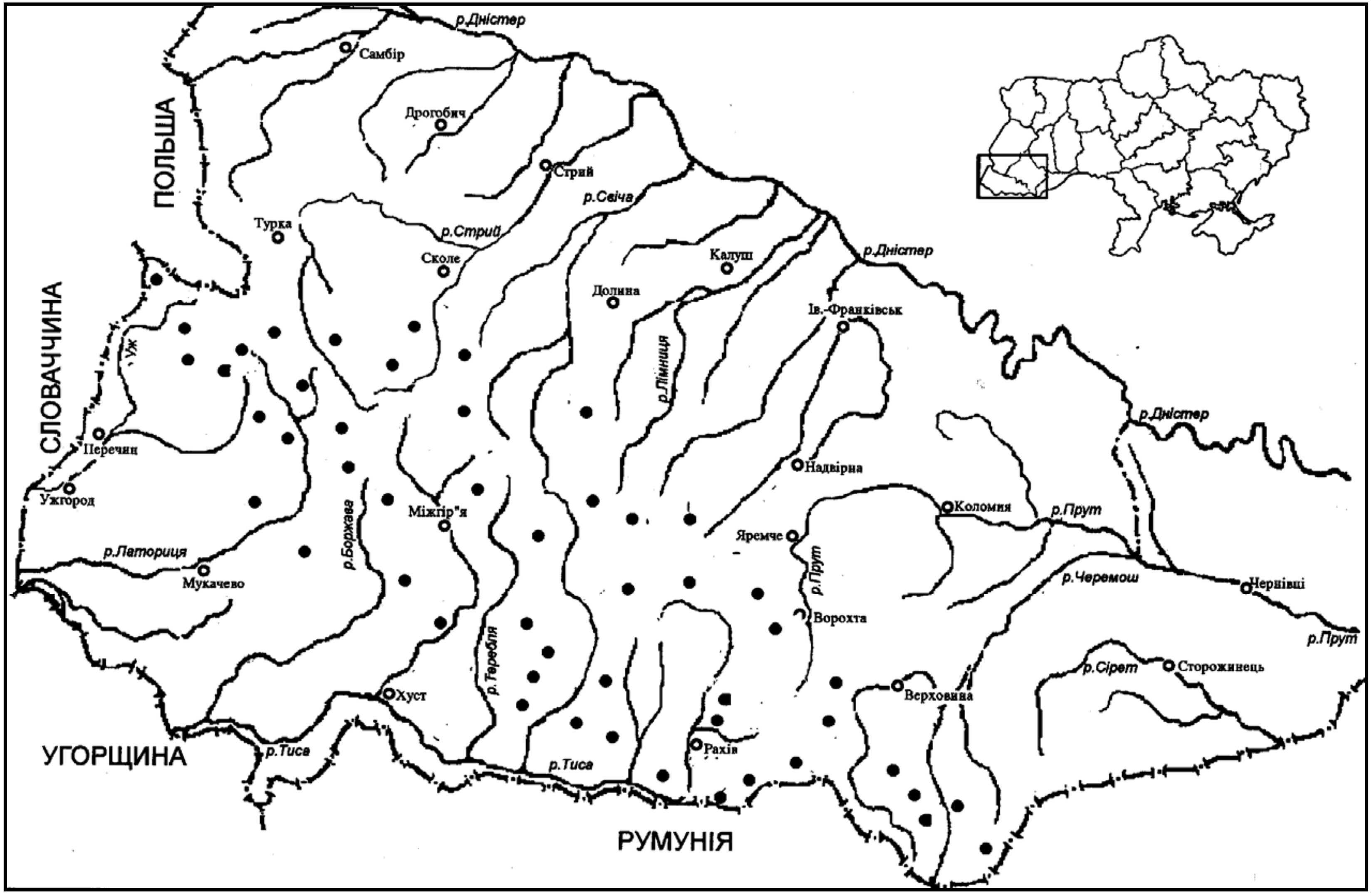
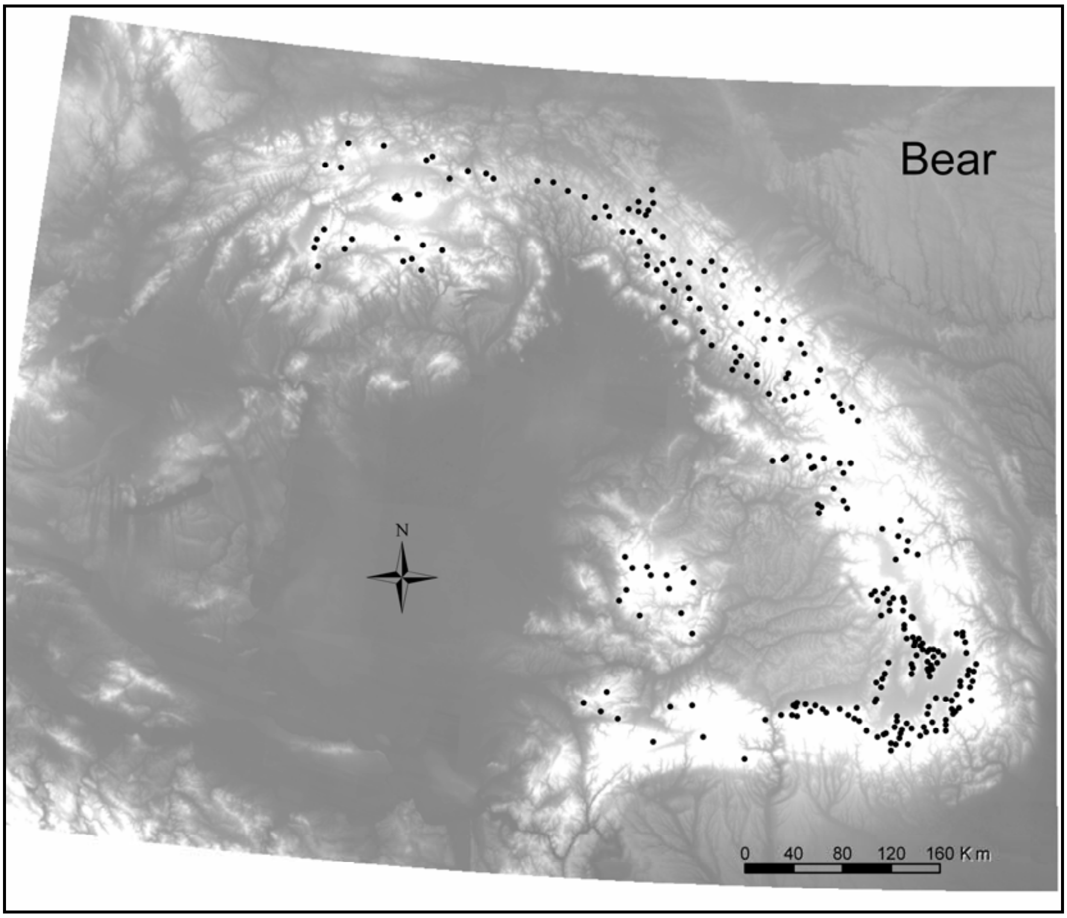


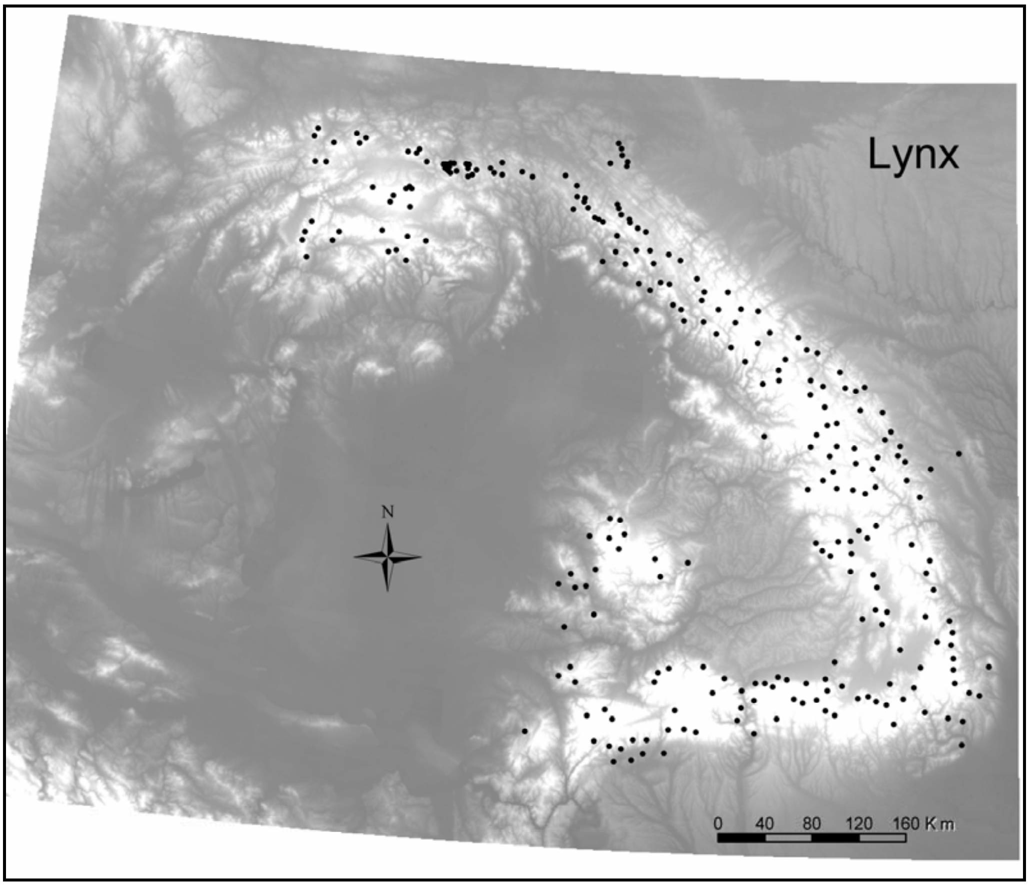
Figure 4.10 – An image of the locations for bear in the Ukrainian Carpathians as provided by the local experts from the Carpathian Biosphere Reserve of Rakhiv. The original data were received in printed format.

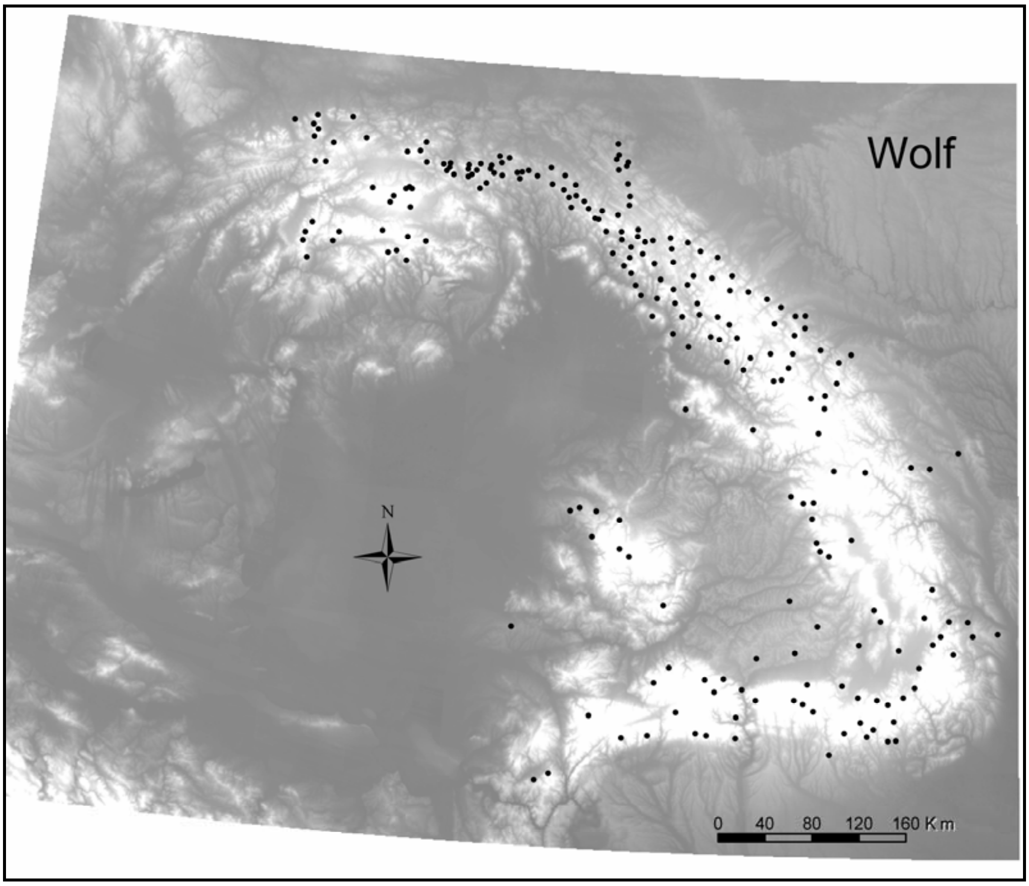
Although the concept of *carnivore location* is assumed to be a discrete (i.e., non-dynamic) one here, the possibility of it being perceived in different ways by humans must be considered. Due to limited funds available, few field surveys of the three carnivores were conducted, particularly in Ukraine. Therefore, the data collected by field biologists that are accurate indicators of the species' presence due to their trained and direct observation or radio-tracking location were available only for the data from Poland and Slovakia, where Dr. Okarma and Dr. Find'o carry out radio-tracking activities on wolves, lynx and bears. In the other countries, the information in form of local expert knowledge needed to be optimised. Despite requesting the most recent information, the level of uncertainty attached to the discrete points of carnivore presence received is difficult to assess. Point locations only provide partial information on presence of animal species, as the recorded location may be visited once, or one that is peripheral and easy to record, and thus reported. This element of uncertainty in the data must be considered at the results discussion phase.

The point locations in the different countries were finally appended into one single layer that was subsequently transformed into raster images. A total of 234, 258 and 224 point-locations were available for bear, lynx and wolf, respectively. Their geographical distribution across the Carpathians is shown in figures 4.11 A to C. Given the extent of the area and the nature of the data, problems associated with autocorrelation of data, and thus pseudoreplications, were considered to be negligible.

Figure 4.11 – The locations where the presence of bear, lynx and wolf was recorded across the Carpathian Mountains. Grey shades represent altitude increasing with darkness. Topographic data from the TOPO 30 data set produced by the USGS web site at 1km spatial resolution.




Lynx
N
0 40 80 120 160 Km


Wolf
N
0 40 80 120 160 Km

4.4 Simulation of the species' perception of space

Once the variables to be used for mapping the environmental suitability for large carnivores in the Carpathians were all standardised and in raster format, they underwent a last pre-processing step that aimed at simulating each species' perception of space.

As already said, some operations included in the processing phase were based on knowledge of the biology of bears, lynx and wolves. For example, the species' presence was often provided as point locations representing direct sightings, track records or radiolocations. Although there was the possibility that they could be placed outside the species' home range, they were assumed to bring information about the species' preferred environment, thus the assumption that they fell inside the home range of the species was made. Assuming that the home range contains all the features that are necessary for the species' survival (see sections 2.4 and 3.2 in chapters 2 and 3, respectively), it can be considered to represent the boundary of the species' perception of appropriate space. This consideration was supported by the fact that most animals do use the home range as a space that they patrol more or less regularly, and within which they are able to find the resources necessary to fulfil all their vital needs (Burt 1943). The individuals thus actually choose to establish themselves in such an area, and most frequently actively defend it from intruders, because they know what the area contains, i.e. they have a perception of the space within their home range (Powell 2000). The concept of the species' perception of space was considered important for mapping environmental suitability, because it gave the opportunity to scale the suitability score to point locations resulting to be suitable that were spatially close to unsuitable areas, thus producing a result that was closer to the reality and providing a complete view of the environment, without risking considering spot locations regardless of what surrounded them.

For taking into account the species' perception of the space, a circular window of a size equal to the size of the home ranges of the target species was used for smoothing the pixel values of the raster images of each variable. In other words, for each pixel the fraction of the presence of the considered variable within a circle equal to the size of the home range was determined (e.g., human disturbance, fig. 4.12) and the raster image was automatically reclassified with continuous values representing the presence of features and the intensity of their presence within the home range window. This concept is not to be confused with the simple linear distance from features at each location. In fact, the linear distance that each location would measure from all the surrounding features would have been complicated to measures and would have required multi-step analyses for considering the distance of each cell from all the surrounding thematic features present on the land within the home range area. The procedure adopted not only considers the distance from each feature of the thematic layer, but also the number of such features present within the smoothing circle representing the home range.

The size of the home range was determined by local scientists who had studied (or are currently doing so) the spatial behaviour of the species by using radio-telemetry techniques (e.g., Okarma 1984, Finďo in prep.). However, such studies were extremely limited and only available for the wolf. The home range estimates for lynx and bear were inferred from those available in other regions of Europe (Breitenmoser *et al.* 2000, Swenson *et al.* 2000). The average home range of wolf in the Carpathians was estimated to be 82 km^2. This represents 84.5% the size of the average home range size of wolves in other parts of Europe (averaged from data in Boitani 2000). This difference may be due to the higher richness of the Carpathian in resources for the wolf: a higher density of ungulates, for example. Under the assumption that the same relationship would hold for bears and lynx, the average home range size of bears and lynx in the Carpathians was considered to be 84.5% of the estimates of average home range of the two species in other areas of Europe (averaged from data in Breitenmoser *et al.* 2000, Swenson *et al.* 2000). The values obtained were 59.9 and 139.3 km^2 for bear and lynx, respectively. The best approximation of these home range sizes achieved with the 250m GIS cells for each species is reported in table 4.3.

Table 4.3 – The sizes of circular windows used in map algebra operations.

Bear		Lynx		Wolf	
Radius (pixels)	Area (km^2)	Radius (pixels)	Area (km^2)	Radius (pixels)	Area (km^2)
17	56.7	26	132.6	20	78.5

The map algebra operation FOCALSUM within the GIS was applied to the variable layers using a circular window of a size coinciding with the average home range size of each species. This operation assigns a value to each cell that results from the sum of cell values within the neighbourhood window. The resulting grid was then divided by the number of cells contained in the circular window, thus averaging the cell values. Through this process, cells that have null value but are close to cells having value 1 (meaning that the variable is present) are associated to a value between 1 and 0 according to the amount of cells with value 1 within the neighbourhood window. This operation simulates the effect that surrounding features have on the pixels, such that, for example, a wolf knows that a road is in the vicinity even if it is not walking on it. The resulting pixel values were converted into percentage values, i.e., the fraction of present variable in the home range or the perception of the presence of the variable by the carnivore. Thus, when applied to the forest thematic layer, for example, these operations produce smoothed cell values that represent the proportion of forest within the large carnivore home range area.

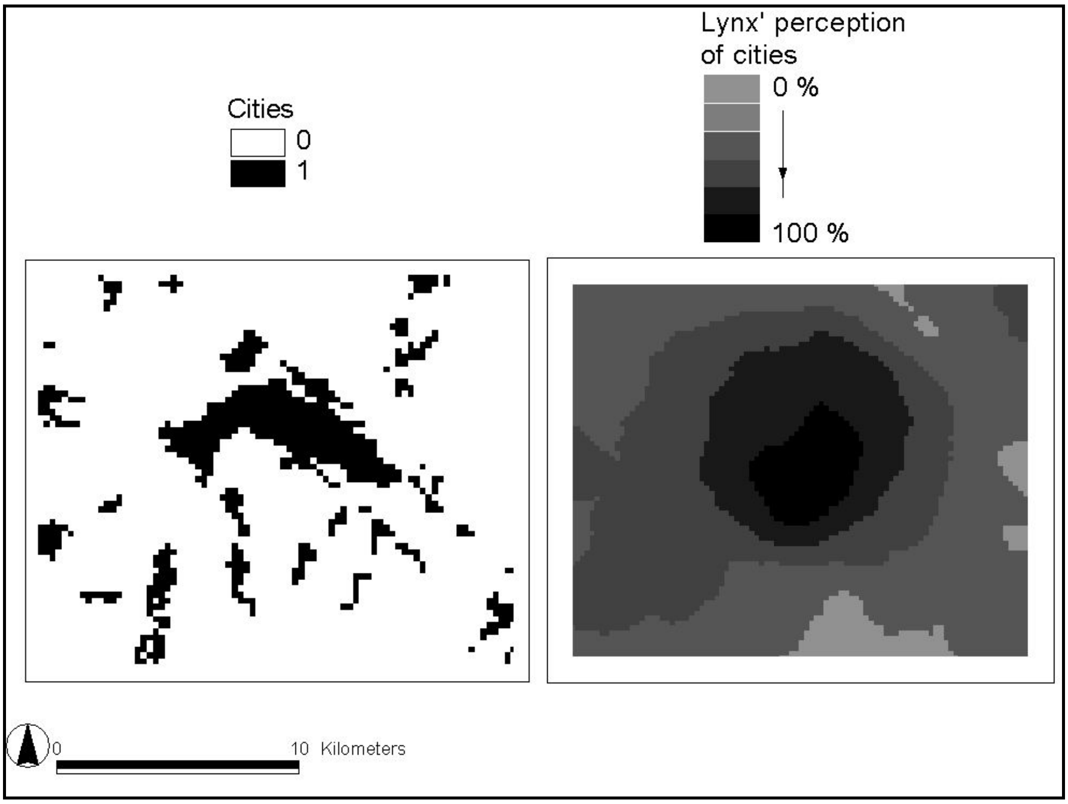


Figure 4.12 – An example of the resulting data after the map algebra operation. On the left, a small portion of the raster image of the cities in the Carpathians is shown, while on the right the same information has undergone the map algebra to simulate the perception of space of lynx, using a circular window of 6.5 km of radius to average the pixel values.

Through this operation, the spatial scale of all the analyses coincides with the average home range size of the species. The shape has been chosen to be circular so as to minimise the edge area, which is usually associated with less suitable habitat (Meffe and Carroll 1997).

Although the steepness and slope of the study area were not derived from the altitude data, their representation was brought in by the pre-processing step that aimed at simulating the species' perception of space. In fact, when raster images represented continuous variables instead of categorical ones (i.e., DEM), the process of smoothing was carried out with a FOCALMEAN operand. The perception of a given feature by the target species was then simulated through the averaging of the cell values for that feature within the neighbourhood window of home range size. In this case, the important information that the DEM brings along is the presence of terrain features that may represent barriers to movements of large carnivores. An abrupt change of altitude values will represent the presence of a cliff, and although the smoothing process decreased the difference hence lessening the abruptness of change, the presence of extreme values of altitude did influence the elevation values in the surrounding cells.

The variables resulting from the smoothing process were then used as inputs for the classification phase. This will be described in the next chapter, with details of the procedure followed and the results obtained.

4.5 Error control

The definition of error as the *difference between reality and its representation* makes it very difficult, if not impossible, to quantify, as is the case when information on reality is not available, or when the representation procedure itself is a simplification of the reality (Heuvelink 1998). As already discussed in section 2.7.1, when data are integrated into a GIS the sources of errors are numerous and occur at all levels of data manipulation, from data input to analysis output (Burrough and McDonnell 1998). The model accuracy, and hence its reliability when used for management purposes, is strictly dependent on the errors from each layer of data carries, and frequently the relationship is not linear (Heuvelink 1998). Although a full error analysis was not performed in the present project, mostly because of the difficulty of assessing the accuracy of source data, which in many cases came without any such information, in this section a discussion of the main sources of error and the possible way to reduce it will be carried out.

- The information on accuracy of Ukrainian data was provided together with the layers and amounted to a maximum error of 140 m. Maps were produced in

1992 and never updated since then. Although the landscape could change noticeably in ten years of time, in Ukraine the rate of development is slow enough to assume that no significant change had occurred.

- Data from Slovakia were produced from topographic maps at 1:50,000 scale, with a digitisation error of 0.1 mm; the maximum spatial error associated was of 10 m.
- No error was associated to data coming from Romania and Poland. An accuracy assessment of data from Romania was performed through comparison of the road layer with the roads digitised by the author from the Landsat 7 image, and the result showed that 40.5% of features were within a distance of 100m, while up to 71% were within 200m distance.

The majority of the reported and estimated errors are within the spatial resolution of the analyses that were performed. Considering that accuracy is a measure relative to the specification, there is no objective threshold for it as it depends on the use made of the analysis output (Veregin 1998). The main objective of the present study was to produce baseline maps that showed the geographical distribution of suitable areas for the conservation of large carnivores in the Carpathian Ecoregion, thus providing a starting point for more accurate, *in-situ* study and management projects. Given the spatial scale of the study, i.e. its extent and spatial resolution, the errors associated to the input thematic data were considered acceptable.

Different considerations apply to the species' locations. Particularly critical were the data from Ukraine, where no field studies are carried out with a scientifically-strong basis (e.g., radio-telemetry), and the scale of the maps provided with the locations were markedly lacking in detail and probably not consistent with the spatial resolution of the rest of the data set. Such data, though, were all that was available, and were obtained after extensive efforts had been made to get a contact in Ukraine that could possibly contribute to the project. The Ukrainian Carpathians are poorly known and the little information available had to be taken as a precious contribution. There is a strong need for better quality data on wildlife presence in Ukraine, where wildlife in general lacks of any kind of monitoring system.

The data on species presence in Poland were considered to be reliable and accurate, although no statistical accuracy check was possible. They came on a tourist map at a scale 1:250,00 and it was assumed that the locational error was a maximum 1mm on the map, as it was a sufficiently detailed to make accurate estimates. No quantification of error was possible for the Slovakian large carnivore locations, as the information came in the form of point coordinates and was successively checked by the person who provided them.

Although most of the known or estimated errors were within the scale of the analysis performed, their interactions throughout the analyses are difficult to estimate. This was particularly problematic during the map algebra operation aimed at simulating the species' perception of space, which resulted in a general smoothing of the environmental variables, thus producing a lost in detail. The precise location of small areas of suitable environment for a large carnivore's presence, though, is of little relevance when considering that those species need large areas for maintaining viable populations. More important is the information about areas of lower suitability that may serve for connecting areas of suitable environment, thus providing potential biocorridors. As already stated, the present study aims at developing a baseline geographical analysis that may serve as starting point for future local actions, thus the location error acceptable may be of few hundred metres. Nevertheless, there is certainly a need for more accurate and, most importantly, error-documented geographical data for Poland and Romania, as well as funds for supporting field study activities on Ukrainian wildlife.

4.6 Conclusions

The selection of variables to be used for mapping environmental suitability for large carnivores in the Carpathians was driven both by ecological knowledge about the target species' biology and by restricted availability of data for the study area. Studying ecological processes across the borders of four different countries represents a challenge *per se* because of the difficulty of acquiring data in a standard format. An intensive pre-processing phase was needed to obtain a database that could be used in the classification phase. Pre-processing steps included standardisation of geographical co-ordinate projection, spatial resolution, interpretation of information provided by local experts and reclassification of information coming from different sources.

The first objective of the pre-processing activities was to produce a database for the Carpathian geographical unit, adequately combining the four component geographical databases coming from the different countries. Even though some sources of data were not available in geographical form (e.g., sketch maps), sufficient information was available to transfer these data into GIS layers. Human presence was derived from topographic information and sufficiently adjusted to the same scale. A DEM could be derived from altitude thematic layers using interpolation techniques.

The carnivores' perception of space was adequately simulated, taking into account that point locations may not provide information on the entire range actually visited by the animals and that discrete features may be perceived by animals within a distance equal to their home ranges. The outputs could be finally used as input for the classifier, which will be described in the next chapter.

5. MAPPING ENVIRONMENTAL SUITABILITY FOR LARGE CARNIVORES

5.1 Introduction

The results obtained from the pre-processing phase described in the previous chapter represented the starting point for the classification phase that aimed at mapping the environmental suitability for large carnivores in the Carpathian Mountains. The present chapter will focus on this classification phase and consequently present the results obtained for the three large carnivore species. Such suitability maps represent one of the main aims of the project and will be discussed in section 5.4. The environmental classification approach will be described in section 5.2, with an introduction reviewing the theory behind the method adopted which is based on the Mahalanobis distance. The following section will describe how discrete suitability classes were established from a continuous output (section 5.3). The accuracy of the classification output was assessed through comparison with a model produced through reclassification of land cover according to suitability scores given by experts, to the consistency with the species' range, and with an independent set of newly collected data on the present location of carnivores. The independent set of data used for validation data resulted from an intensive field campaign that involved travelling throughout the Carpathians. The results of the validation will be presented and discussed in section 5.5.

5.2 The mapping phase

In order to map the distribution of potentially-suitable areas for the conservation of large carnivores an inductive approach (Stoms *et al.* 1992) was adopted. The process resulted in the assignment of a suitability degree to different combinations of environmental characteristics that were compared with a set of values assumed to be highly suitable for the large carnivores. Given the paucity of available data on large carnivores in this part of Europe, and the chronic lack of detailed field studies that could provide reliable data upon which to build unequivocal relationships, the available presence locations obtained by the experts needed to be exploited to the full. The process of building up the knowledge base that is aimed at maximising the available information about the species in the study area makes such an exploratory study in an area where detailed information is necessary, extremely important.

The procedure adopted in this study is based on the one used by Institute of Applied Ecology (IEA 1998), and includes a training phase and a classification phase. However, there are some essential differences between the procedure followed by IEA (1998) and the one followed in the present study. The differences are mainly due to the nature of available data on large carnivores in the Carpathians; and they represent improvements that could also be applied wherever there are similar data sets available. Also, the difference in the availability of geographical data across the Carpathian countries has represented an opportunity for innovative work in this project. In IEA (1998) the authors mapped the environmental suitability for large carnivores in the Alps using information from experts who had been studying the target species in the field for many years. Thus they were able to provide plots of home range extents of wolf, lynx and bear in the area. These were used as a source of information about the environmental conditions preferred by the species in the Alps. However, mapping the home ranges of the carnivores was not possible in the present study because of the lack of radio-tracking data, thus a procedure for indirectly estimating the home range size of the carnivores in the study area was undertaken using data from other European countries. This was coupled with an intensive effort to obtain information from local foresters and hunters, who, although not able to provide scientifically-based information, gave a significant contribution. The present study, thus, has included a noticeable collaboration effort with local researchers and governmental institutions, leading to a significant phase of management skills development. The identification of potential contributors to the project was catalysed by contact made with the members of the Large Carnivore Initiative for Europe (LCIE), coordinated by WWF International, which funded the present project. The members of the LCIE are mostly researchers and wildlife managers who are actively involved in research and management of large carnivores in 29 countries of Europe. The main contacts for Poland, Slovakia and Romania were made through the presentation of the project to the LCIE meeting held in Cuneo (Italy) in September 1999. Other contacts were necessary for gathering geographical data as well as detailed carnivore presence data throughout the countries visited. Such contacts were made under agreements of collaboration and data sharing with some collaborators, or under payment of local students and colleagues. The experience of very limited resources that most local researchers have, made the selection of data obtained under payment sometimes tricky. In fact, in many occasions local counterparts would agree to provide data even if they knew they were unable to provide them at acceptable standards. Thus the selection of reliable sources and partners required an intensive phase of investigation on whether they actually had the means to provide the data with the required reliability.

A crucial innovation of the current project was that it included an intensive validation phase, while the results obtained for the Alps were not validated, thus it was possible to provide a measure of reliability of the results obtained using newly-collected data, and contributing to the test of a technique that has the potential to be easily applied in all kinds of environments.

5.2.1 The classification approach

The classification of suitable areas for large carnivores in the Carpathians was performed using a distance classifier that compared the characteristics of each point in the area to the centroid of the distribution of carnivores' locations. Given the fact that the environmental variables are usually correlated (and the correlation is seldom a linear one), the Euclidean distance would not have been appropriate (De Maesschalck *et al.* 2000). Hence I used the Mahalanobis distance, a multivariate technique used to measure the distance of a single multivariate observation from the centroid of its multivariate population (De Maesschalck *et al.* 2000, Manly 1994). Taking in consideration the variance and, most importantly, the covariance of the variables measured, it is able to take into account the correlation between them. Similar techniques are used in remote sensing for classification of satellite images, whereby a range of reflectance values is associated to a feature class and the multivariate distance assigns the pixels of the image to the class through a minimum distance procedure, according to the distance of the pixel values from those of the reference values (Campbell 1996, p. 323). Other applications of the Mahalanobis distance include the identification of outliers of sample sets that may be used for training classification procedures (Mather 1999, p. 177), and the investigation of representativity between two data sets (Jouan-Rimbaud *et al*. 1998). The procedure for mapping of environmental suitability for large carnivores with the Mahalanobis distance can be compared with a maximum likelihood classification, where the range of reflectance values of the classification are replaced by the values of the environmental variables at the carnivore location points, belonging to the most suitable environment (ecological signature) class in the suitability map. In other words, each point may be considered as a vector in a multi-dimensional space, where the dimensions are environmental variables and the Mahalanobis distance between each vector and the vector selected to represent the most suitable environment is a measure of the similarity of such vector to that of the reference. Thus the Mahalanobis distance becomes a measure of environmental suitability for carnivores. The Mahalanobis distance considers the statistical variation explained by each variable and uses it for describing the axes of an ellipsoid in the feature space that contains all the measured locations.

The advantages of using the Mahalanobis distance instead of the Euclidean distance are that (i) the variance-covariance matrices are not required to be equal, a condition often difficult to meet with ecological data (Clark *et al.* 1993); (ii) the variability of environmental characteristics is considered with the variance; (iii) the correlation among covariates is included in the covariance; (iv) if the covariates are normally distributed the distribution of the Mahalanobis distance will follow a chi-squared distribution (Manly 1994) and the output values can be considered as probability values (Clark *et al.* 1993).

The procedure of using the Mahalanobis distance to map environmental suitability consists of two steps, the training phase and the classification phase. They will be explained below.

5.2.1.1 The training phase

Although little published information is available on the Carpathian population of large carnivores, the local knowledge about the biology, behaviour and presence of the species target of the present study is abundant. The selection of environmental variables that describe the distribution of the three carnivores was driven by information about the behaviour of the carnivores gathered from local experts and published literature (see section 4.2 in chapter 4), and by their availability in digital and hardcopy formats.

The data coming from local experts on the species' presence were used to train the classifier towards the definition of the species' *ecological signature*. In order to do this, it was assumed that the areas where the large carnivores' presence was recorded represented the "optimum" set of environmental characteristics among all those possibly available in the study area. The assumption has one drawback because it considers the variables found in the areas where the species' presence has been recorded at any given time and does not guarantee that the species' presence was recorded only in the optimum conditions within their area of occupancy. However, this drawback was mitigated by averaging the values within a set of locations across the whole study area. This allowed the consideration of the scenario variability, where different scenarios may be equally suitable for a given species. The multivariate nature of the data was represented by a vector in a multidimensional space (with as many dimensions as the number of variables used). The mean value used for each variable was derived from all locations where each of the carnivores was recorded. This average vector would then represent the *ecological signature* of each species within the study area and was consequently used in the classification phase.

5.2.1.2 The classification phase

The *ecological signature* was used in the classification phase as reference vector against which the degree of suitability of the environmental variables considered was measured. The procedure can be thought of as being a classification of raster images using a distance classifier, whereby any one pixel is allocated to a given class according to the similarity to the training signature of one or another class (Lillesand and Kiefer 2000, p. 538). In the case of the present study, such a similarity value represents a measure of how far away any given pixel is from the "suitable" class or ecological signature.

A fundamental assumption when using this approach is that the current distribution of species both precisely explains, and is explained by, historical, environmental and behavioural processes. Thus, causative processes are not identified: however, suitability is instead represented by the characteristics of locations where species were present without attempting to explain why they are present (inductive approach).

The ecological signature was used as reference vector from which a measure of distance can be determined using the Mahalanobis multivariate approach. Each pixel is represented by a multidimensional vector defined by the environmental characteristics at its location. This method considers the *optimum vector,* which is the *mean* value (**m**) of the variables at sites where species are present, the variance-covariance matrix (**S**) of environmental variables can also be determined. Thus, the distance between each pixel's vector (**x**) and the reference vector (**m**) is given by the Mahalanobis distance as (Fig. 5.1):

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

Where $D^2(x)$ is the squared distance of the x^{th} vector from the reference vector, and $S^{-1}(x-m)'$ is the estimated inverse covariance matrix.

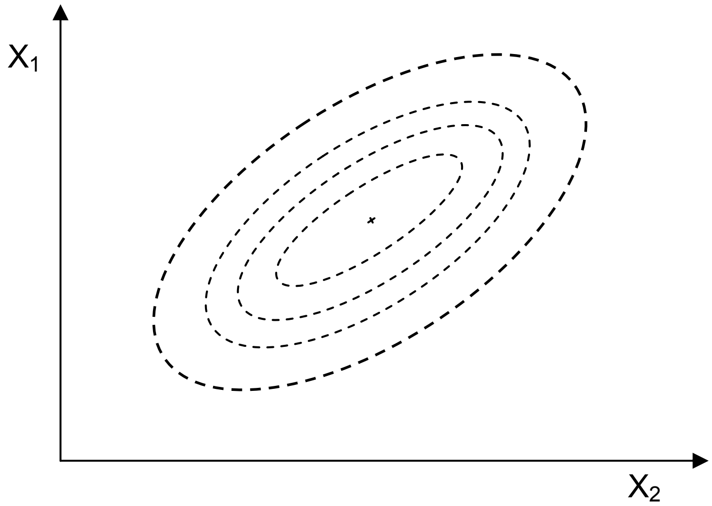


Figure 5.1 – Plot of the Mahalanobis distance against any two correlated variables, where the cross represents the centroid and the lines are isopleths of distance values. The Mahalanobis distance (D^2) would only be equivalent to the Euclidean distance in the special case of uncorrelated variables and equal variances in all directions. In such a case, the plot of isopleths will be represented by circles around the centroid. (Modified from De Maesschalck 2000).

The Mahalanobis distance is calculated through equation (1) and in the process of calculation the variance-covariance matrix of all variables is computed. This is taken into account through the process in such a way that the part of a variable already explained by another correlated one is subtracted from the calculus, thus avoiding the consideration of pseudo variability (De Maesschalck 2000).

The result is a map of values defining the distance from the optimum environmental conditions for each pixel. This can be used as a measure of the suitability of each pixel for the presence of each species. The values associated with each pixel are dimensionless and only have meaning when related to the reference vector representing the ecological signature. As each map is derived from species-specific data, they cannot meaningfully be compared with each other, unless being appropriately standardised (e.g., transformed into percentages).

5.3 The establishment of suitability classes

The outputs produced by the Mahalanobis distance (D^2) assume continuous values that potentially range from 0 to infinity. The procedure used here was developed by Dr. A. De Biase at University of Rome “La Sapienza” in C-language following the matrix algebra operations, and allows the user to establish some settings, such as which variables to use and the maximum value D^2 can assume. Thus the outputs, directly created in Arc-View as grid images, range from 0 to the set maximum distance value. Subsequently, threshold slicing was used to split such values into suitability classes in order to set the boundaries of environmental suitability. This was done following an approach that aimed at being as objective as possible. The mean and standard deviation (SD) of the D^2 values at the locations where the presence of each species was recorded were calculated and used for the slicing process such that 7 classes were established as follows:

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

Because it is based on the values of the mean and the standard deviation, such an approach assumes that the D^2 values at presence locations are normally distributed. The distributions of D^2 values at the location of the three carnivores were tested for normality using the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). When the normality assumption was not satisfied, the mean and SD values were replaced with the modal and upper quartile values, respectively. The mode was used because the distributions of the D^2 values were strongly skewed towards low values. This is expected, as they are the locations that supposedly have the highest suitability, thus minimum values of D^2. The distribution of the D^2 values at locations of bears, lynx and wolf are sketched in figure 5.2 and the distribution parameters are reported in table 5.1.

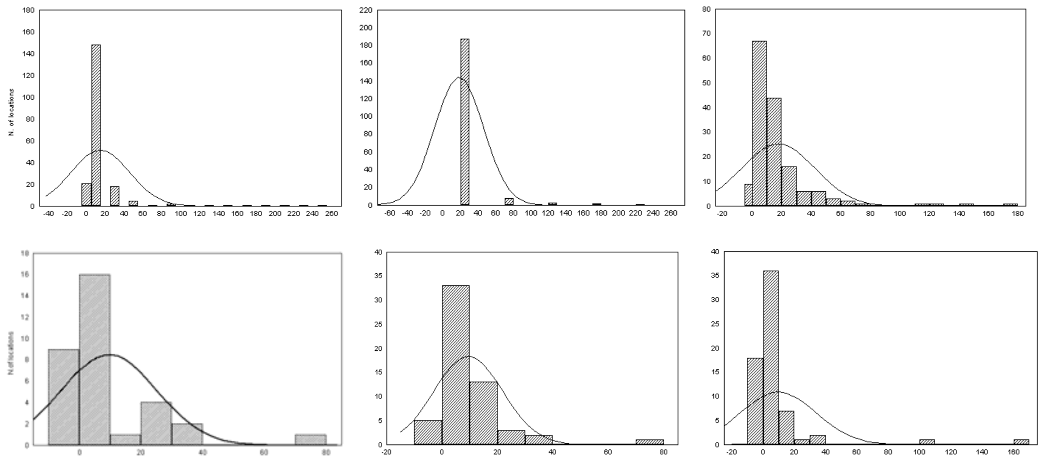


Figure 5.2 – The frequency distribution of D^2 values corresponding to the carnivore locations. Uppermost graphs are relative to the area of the Slovak-Ukrainian-Romanian Carpathians, while lower ones are relative to the Polish area. From left to right, the graphs represent value for bear, lynx and wolf, respectively. The continuous line represents the expected normal distribution.

The results from the normality distribution tests are reported in table 5.1, together with the values of mean and standard deviation as well as the median and upper quartile.

	BEAR		LYNX		WOLF	
	SK-UA-RO	PL	SK-UA-RO	PL	SK-UA-RO	PL
Total n.	200	33	199	57	156	66
mean	14.3	9.5	17.9	9.4	17.5	9.5
sd	30.9	15.4	27	12.4	24.9	24.1
mode	6	3	10	5	11	3
upper quartile	14	8	18	13	19	8
Normality test	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01

Table 5.1 – The distribution parameters of the D^2 values at carnivores' locations used for thresholding the Mahalanobis distance into suitability classes. For each species values are reported relative to the Carpathian area of Slovakia, Ukraine and Romania and for the Polish Carpathians separately as they were produced using different sets of environmental variables (see section 4.3.3). The probability values resulted from the test performed in order to check for normality distribution through a Kolmogorov-Smirnov and Shapiro-Wilk tests (Sokal and Rohlf 1995).

The results are separate for Poland and the rest of the Carpathians because of the lack of altitude data for Poland that could affect the overall value of the optimum vector. Thus the calculation of the class thresholds and the slicing process were performed on the two areas previously to the merging of the resulting classified map.

5.4 Classification output

The outputs generated by the Mahalanobis distance showed that a large part of the Carpathian Region is suitable for the three carnivores.
The data from the land cover raster were subset over an area that included the Carpathians entirely. The area obtained covers 340,165 km^2 and includes the Carpathian Ecoregion. The proportions of areas associated with different suitability classes were calculated within the area of the Ecoregion only, which extends over 189,611 km^2. The boundary of the Ecoregion is shown in fig. 5.3. The results will be reported below on a per species basis, i.e., the proportion of the Carpathians included in each suitability class for the bear, lynx and wolf. This is followed by a description of how the three raster-images were combined to produce a map representing the synergetic result of simultaneous suitability for the three species.

In order to understand the geographical locations of reference features that will be mentioned in the discussion of the results obtained, figure 5.3 shows few major cities, the country boundaries, the extent of the Carpathian Ecoregion, and the major protected area of the region: the trilateral reserve of the Biosphere including the Uzhansky National Park in Ukraine, Poloniny National Park in Slovakia and Bieszczady National Park in Poland.

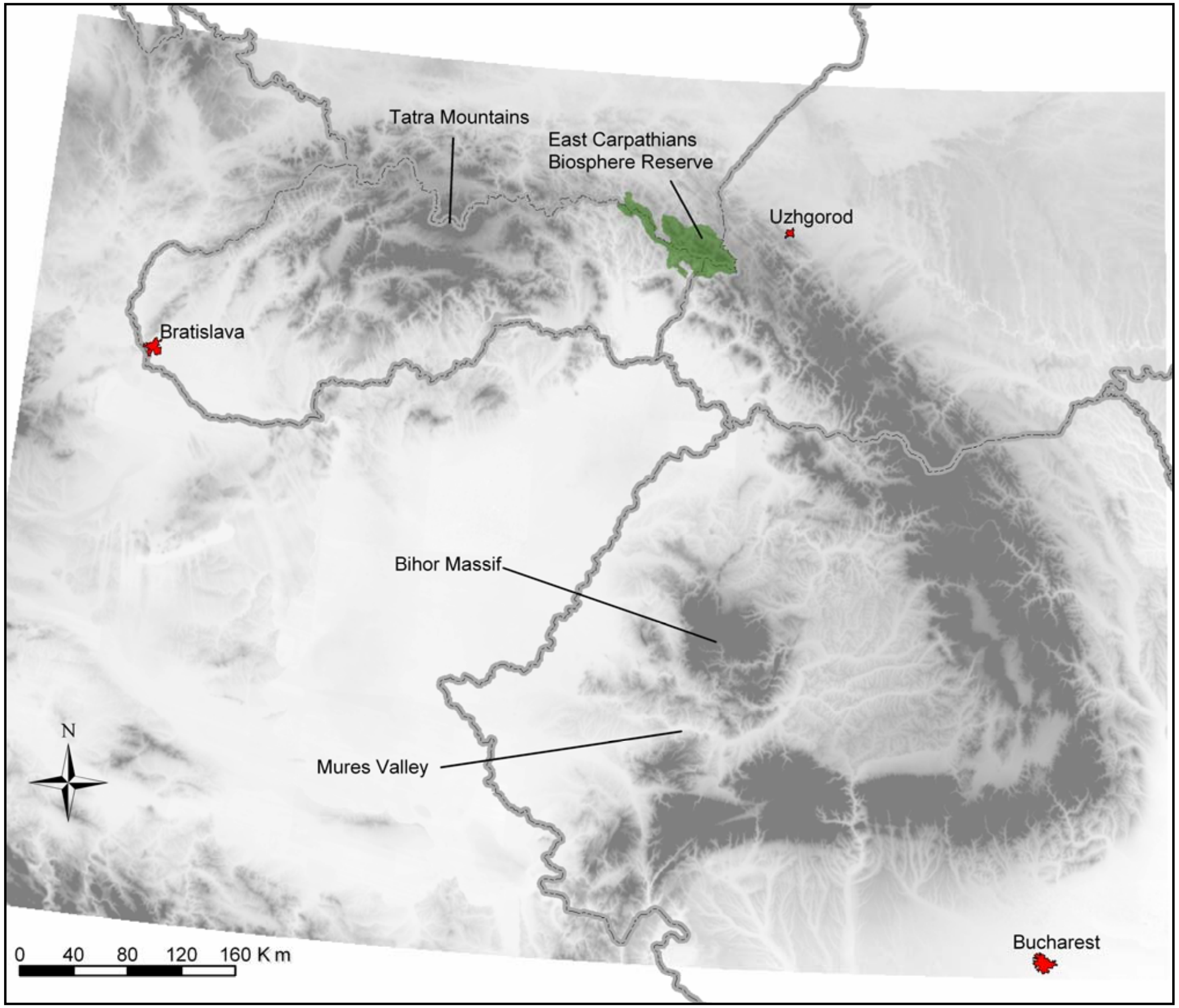


Figure 5.3 – The Carpathian Mountains represented by the Digital Elevation Model at 1km resolution produced by the USGS. The location of some of the major features is reported, for ease of interpretation during the discussion of the results obtained through the classification phase.

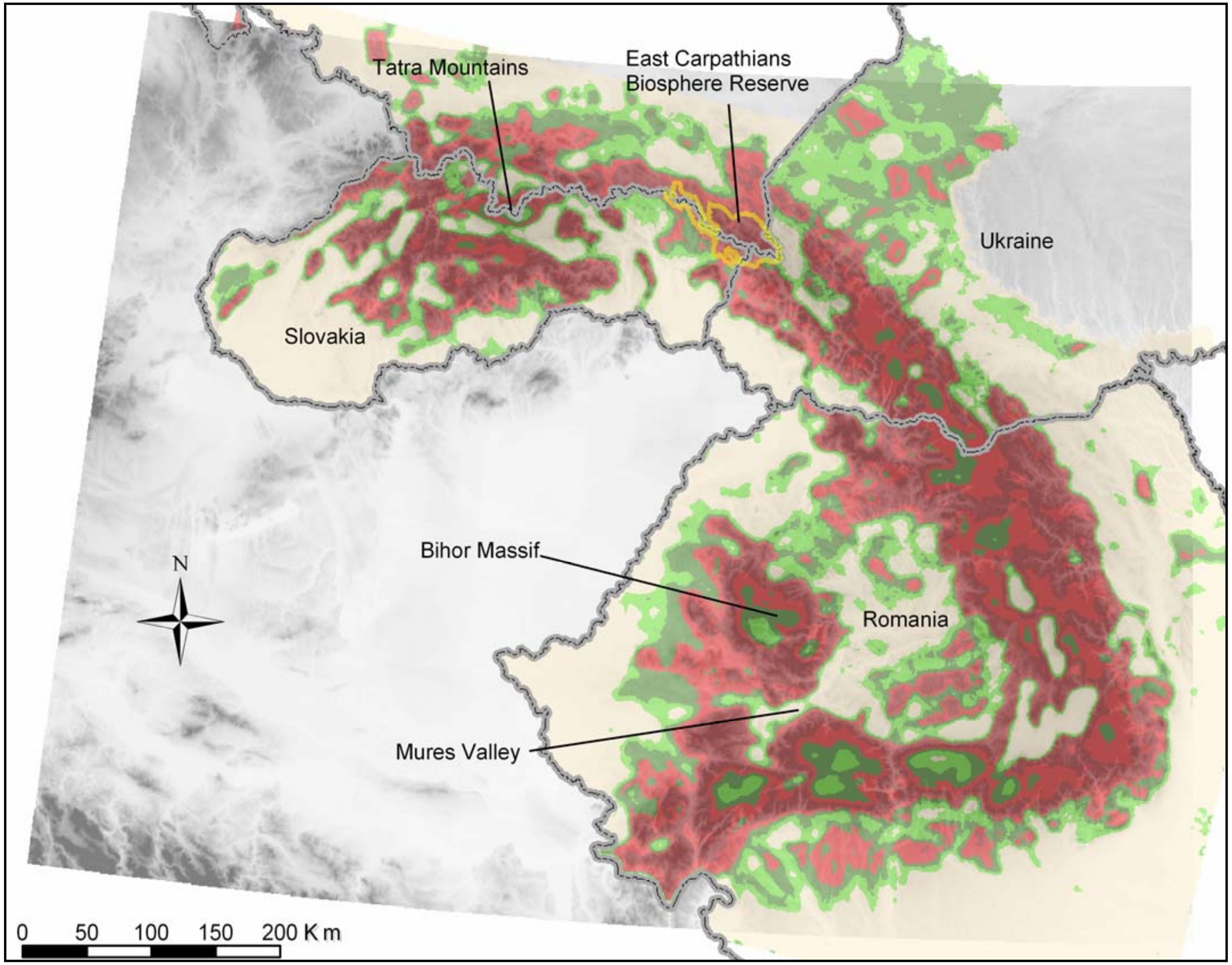


Figure 5.4 – The graphic representation of the classification output for bear.

5.4.1 Bear

The map produced for the bear suggests that the Carpathians have large portions of suitable environment for this species. Figure 5.4 shows the suitability map of the classification output. An area of 36,384 km^2 in the Carpathians is classified with the highest suitability for the bear, corresponding to 18.7% of the Ecoregion. The second most suitable class covers an area of 42,268 km^2, equal to 22.3% of the Ecoregion. Figure 5.5 shows the percentage of area belonging to the different suitability classes within the Carpathian Ecoregion.

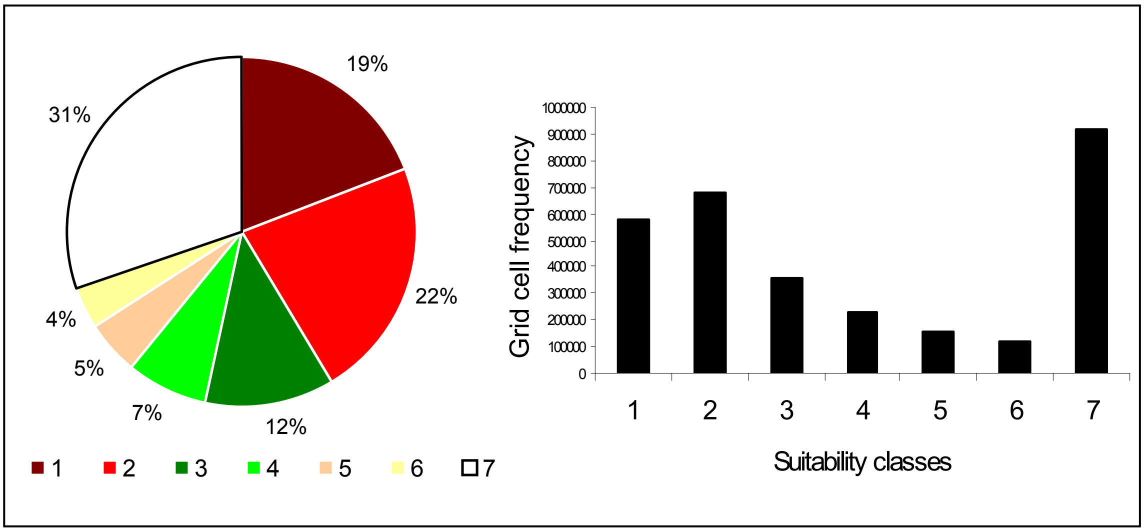


Figure 5.5 – The percentage area of the Carpathians and the cell frequency (size 250x250m) included in the suitability classes for bear as classified by the Mahalanobis distance. Classes 1 to 7 indicate high to low environmental suitability.

The most suitable class is made up of 154 patches of average extent over 353 (SD = 2597) km^2 and separated from each other by an average distance of 1.9 (SD = 3.2) km. The second most suitable class is in total larger than the most suitable one, and formed by 411 patches of 121 (SD = 1065) km^2 mean size. Finally, the least suitable class covers 57,576 km^2, an area that accounts for 31% of the whole Carpathians. It contains 528 patches with an average area of 90.5 (SD = 742) km^2 and the distance between them averages to 2.3 (SD = 3.3) km.

The values of percentage of forest and urban presence at the training location averaged 74.9% (SD = 15.7) and 1.8% (SD = 1.5), respectively. These values suggest a degree of adaptability to the variation in forest cover (fig. 5.6), which needs to be at considerably high levels, and a little adaptation to the presence of urban areas. The presence of high forest cover is certainly characteristic of low D^2 values, but there is a high degree of variability in percentage of forest cover within the scale of D^2 values (fig. 5.6). The presence of urban areas, on the other hand, seems to be constantly avoided in areas of high suitability, while it increases towards higher values of D^2, thus suggesting a stronger influence of the presence/absence of urban areas as a variable for determining habitat suitability for bears in the Carpathians.

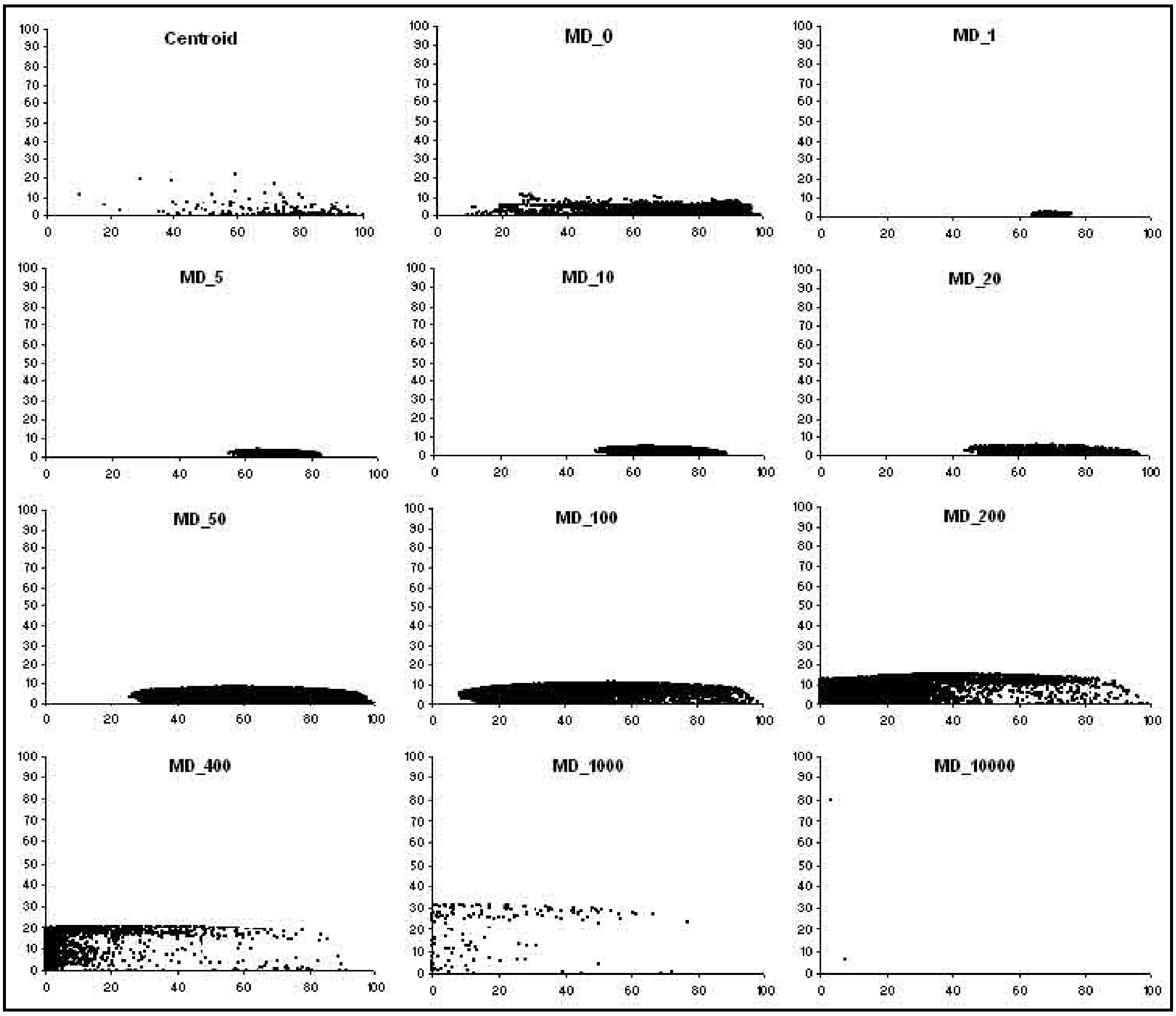


Figure 5.6 – Plots of points of equal Mahalanobis distance value against forest (X axis) and urban areas (Y axis) percentage of presence. Only D^2 values of 0, 1, 5, 10, 20, 50, 100, 200, 400, 1000 and 10000 are reported.

The overall situation appears to be favourable for the bears in the Carpathians, as the average size of the “best” environment patches is much larger than the average bear’s home range (estimated to be 59.9 km^2, see section 4.4 in chapter 4) and they are separated by a distance that is less than half the radius of an hypothetically circular bear's home range.

There is also a spatial pattern in the distribution of patches of high suitability. They are mainly distributed over the mountainous areas, never occurring at altitudes lower than 200m a.s.l. and the average altitude of the areas classified as most suitable is 887m a.s.l. (SD = 206). Noticeable features are the low suitability values associated with the area of the Transylvanian Plain, situated in the elbow of the Carpathian chain, and the isolated Bihor massif in Western Romania (fig. 5.3). The latter is classified as highly suitable, but it is separated from the rest of the mountain range by the Mureş river valley, which functions as a natural barrier (Moraru *et al.* 1966), and assumes low suitability values.

Going north along the mountain chain, the suitable areas of classes 1 and 2 intersperse with each other almost regularly until they reach the mid-Ukrainian Carpathian region, where the area surrounding the city of Uzhgorod presents a highly developed environment associated with low environmental suitability for bears. The connection between suitable areas in Ukraine and Poland is very limited, and only present in correspondence with the Uzhansky National park, which is part of the tri-lateral UNESCO Biosphere Reserve "East Carpathians" and continues in Poland with the Bieszczady National Park and in Slovakia with Poloniny National Park. It should be noted, though, that the physical border between the Polish and Ukrainian sides of the Biosphere is marked by a metal net fence that does not allow free animal movement, and vegetation is cleared for a few meters around the fence, thus greatly altering the natural environment.

The Slovak portion of suitable areas for bear is extremely fragmented, and mainly limited to the western portion of the mountainous area. The eastern part of Slovakia is less developed, but small villages and settlements are scattered over large areas. This part of Slovakia is also more rural, and the presence of bears may conflict with production of fruits and honey.

Poland has only one large area of suitable environment that is worth noting, and it coincides with the Bieszczady National Park. This is a very wild area with extremely low human population density due to deportations of local minorities during World War Two, and it is now one of the few places in Europe where the European Bison (*Bison bonasus*) exists after a reintroduction programme developed in the late 1960s. The rest of the highly suitable areas in the Polish Carpathians may represent an important element for connecting the westernmost regions of Slovakia and the northernmost areas of Ukraine. It should be remembered that the altitude data for Poland were not available, and the results may be inaccurate for that portion of the Carpathians. Although the altitude data for Poland were available from the USGS, they were at 1 km resolution, thus using them would have degraded the spatial resolution of the whole database, thus converting it into 1km resolution instead of 250m. The results obtained through this mapping process allow an identification of bear distribution at a level of detail that was not available previous to this study, thus highlighting the valuable contribution to the management of this emblematic carnivore.

5.4.2 Lynx

The results obtained for lynx indicate that nearly half of the Carpathian region is environmentally suitable for the largest cat of Europe. The map of the classification output is shown in fig. 5.7, where the geographical distribution of the areas associated with each suitability class are displayed.

The first most suitable class is distributed mostly in Romania and Slovakia. A very small portion of Poland is classified as highly suitable. Class 1 is made up of 107 patches of 484 (SD = 2988) km^2 mean size and the average distance between them is 1.3 (SD = 2.6) km. The second most suitable class is made up of 234 patches of 216 (SD = 1672) km^2 mean size and separated by an average distance of 0.8 (SD = 1.7) km.

The first and second suitability classes cover areas of 64,3543 and 44,934 km^2 (34% and 24% of Carpathians), respectively. The remaining 42% of Carpathians is classified as suitability classes 3 to 7, which could be considered medium to low suitability (fig. 5.8).

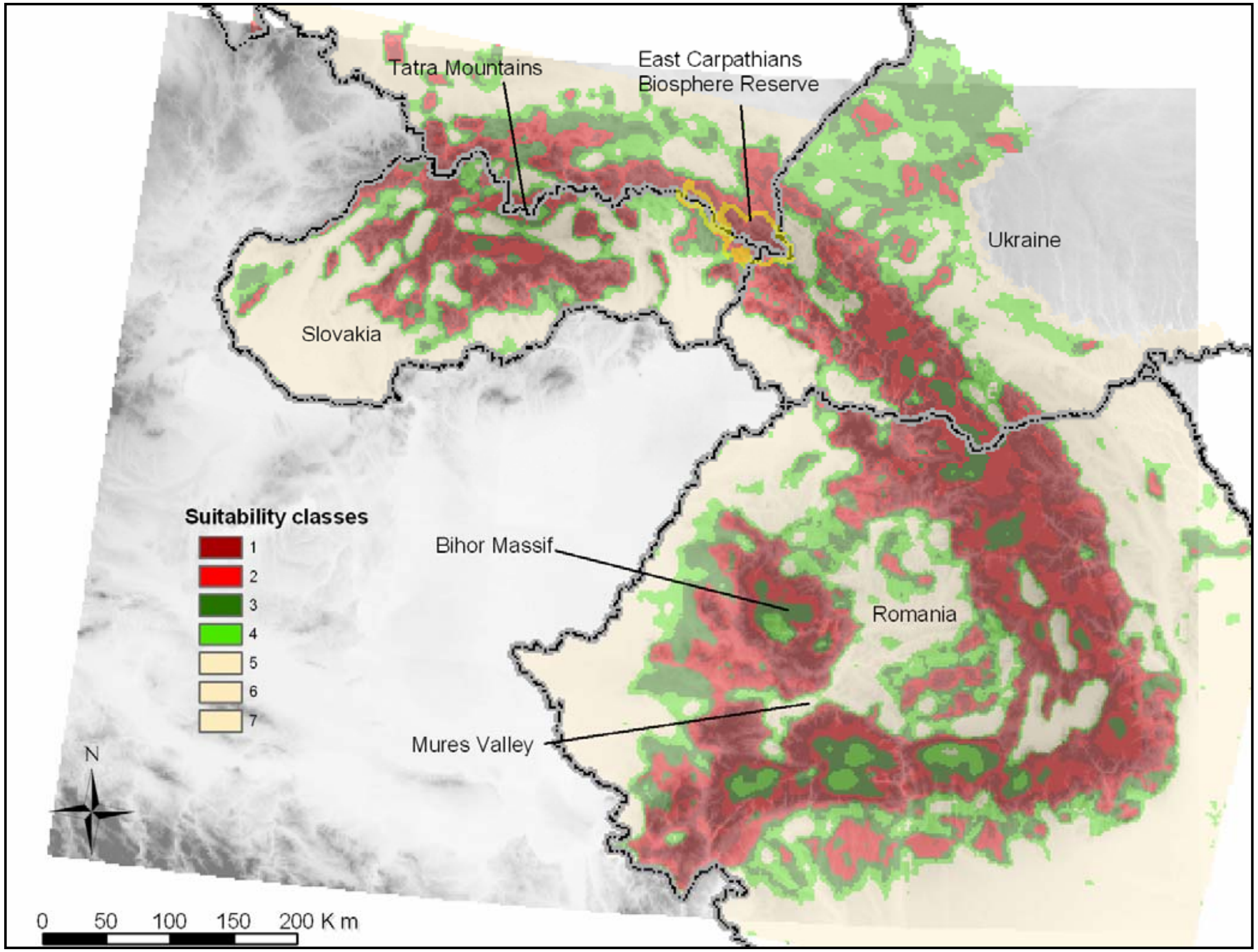


Figure 5.7 – The graphic representation of the classification output for lynx.

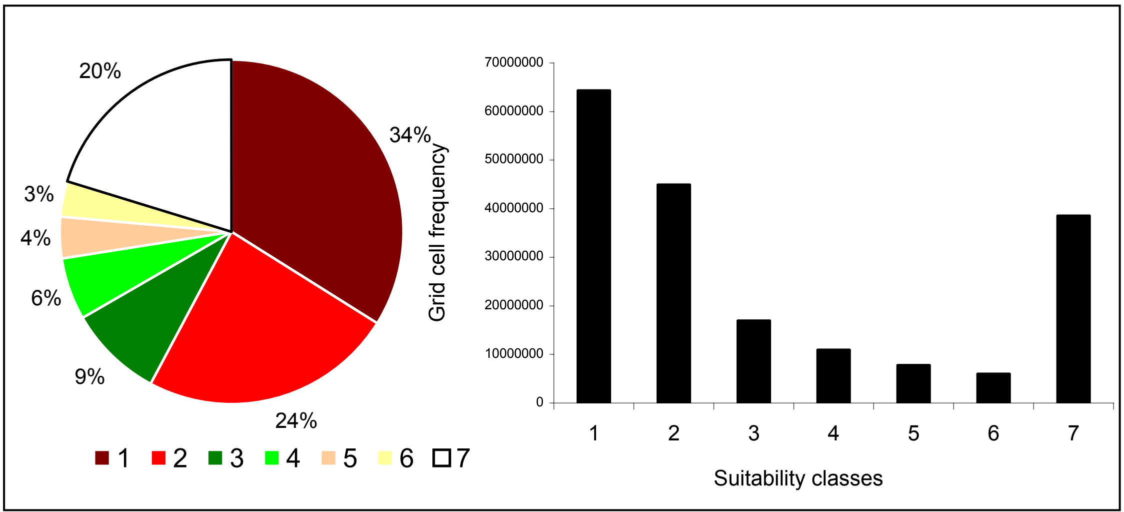


Figure 5.8 – The percentage area of the Carpathians included in the suitability classes for lynx as estimated by the Mahalanobis distance. Classes 1 to 7 indicate environmental suitability high to low.

More than half of the Carpathians were classified as of high to medium-high suitability for lynx. The patches of the highest suitability class have an average size that is nearly four times the size of a lynx' home range (139.3 km^2, see section 4.4 in chapter 4). Furthermore, they are mainly interspersed with areas of class 2, thus not likely to incur a process of isolation. The patches are also separated by relatively short distances, which are within the range of mean distances travelled by lynx, i.e., 1- 45 km (Breitenmoser *et al.* 2000).

The Bihor Massif of Romania is linked to the rest of the Southern Carpathians only by a small area of suitability class 2, and the Mureş River may act as a barrier (fig. 5.3), although lynx may be able to cross the water. The Transylvania plain appears to be highly unsuitable, most probably due to the lack of forest cover. Lynx need large home ranges and are secretive animals. The fragmentation of suitable areas, with a subsequent decline of sizable prey populations, may be severely threatening the survival of this valuable species (Breitenmoser *et al.* 2000). Human disturbance as well as the availability of prey may have a strong influence in the selection of areas to be occupied. Lynx have a specialised diet, strictly carnivorous, and the unavailability of data on the distribution of prey may be a source of error in the classification process.

The spatial distribution of the suitable areas for lynx follows the mountain range, with altitudes averaging 777 (SD = 224) meters a.s.l., and reaching values as low as 60 m a.s.l. This may be due to the large areas needed by lynx, which often include areas of high altitude, but mainly to the particular sensibility of lynx to human disturbance, which is least in high mountain areas. The high suitability areas in the Ukrainian Carpathians are continuous to those in Romania, although the plain of Uzhgorod and surrounding towns represents a large gap of unsuitable area. Very little continuity between the suitable area of Poland and those of Ukraine is present, even in the UNESCO International Biosphere Reserve “East Carpathians” that includes the three protected areas of Uzhansky (Ukraine) – Bieszczady (Poland) – Poloniny (Slovakia). Such continuity, however, is present on the Polish-Slovak border.

The Polish Carpathians seem to be the only part of the Northern portion of the Carpathian Region to be highly suitable for lynx, as the Eastern part of Slovakia is very rarely suitable. However, the suitable areas increase in western Slovakia. It is interesting to note that this area is the source of the re-introduced lynx in the Swiss Alps. Apart from a large highly suitable patch in western Slovakia, the fragmentation of suitable environment is high in the northern part of the Carpathians.

5.4.3 Wolf

The Carpathians are largely classified as sub-optimal to optimal (classes 1 and 2) for wolves. The first and second suitability classes cover areas of 79,567 and 44,489 km^2 (42% and 23% of Carpathians), respectively. Only 14% of Carpathians is classified as not suitable (class 7).

The map of the suitability classification output is shown in figure 5.9. Class 1 is made up of 184 patches of 432 (SD = 1395) km^2 mean size and the average distance between them is 0.4 (SD = 0.3) km. The second suitability class is made up of 397 patches of 112 (SD = 277.34) km^2 mean size and separated by an average distance of 0.4 (SD = 0.3) km.

The large proportion of Carpathians classified to be suitable reflects the broad ecological valence[1] of the wolf. In fact, the species is highly adaptable to diverse environmental conditions and its presence seems to be regulated by the presence of food sources rather than environmental conditions (Boitani 2000). Human persecution is the limiting factor for wolf presence, and probably the most difficult variable to measure for use in a GIS mapping process. Various indices of the effect of human presence can be used and Mech *et al.* (1988) and Mladenoff

[1] The ecological valence can be considered as the variety of environmental conditions within which an organism can survive and replace itself, or a process can function.

et al. (1995) have developed models for wolf habitat suitability suggesting that road density was the limiting factor for habitat suitability. Although road density may be used as an index of human presence, the effects of the latter are not always negative on wolf presence, as human attitude towards wildlife may change according to many factors and data representing this attitude are difficult to obtain. Given the adaptability of the wolf, the first and second suitability classes were considered as generally highly suitable for species. As with the other species, the spatial distribution of suitable areas follows the pattern of mountainous areas, showing a nearly continuous distribution along the mountain chain.

The Bihor Massif of Western Romania is connected to the rest of the southern Carpathians by a small section of suitable area, but the isolation of the wolf population into small fragment does not seem to be a threat to the Carpathian wolf, because of the extension of suitable areas and the adaptability of the species.

The Transylvanian plain represents a gap in the continuous suitable area of the Southern Carpathians, that extends along the Eastern portion and into Ukraine with nearly no gaps until the Uzhgorod area in Central Ukrainian Transcarpathia region.

The overall percentages of the Carpathians covered by each class are shown in figure 5.10.

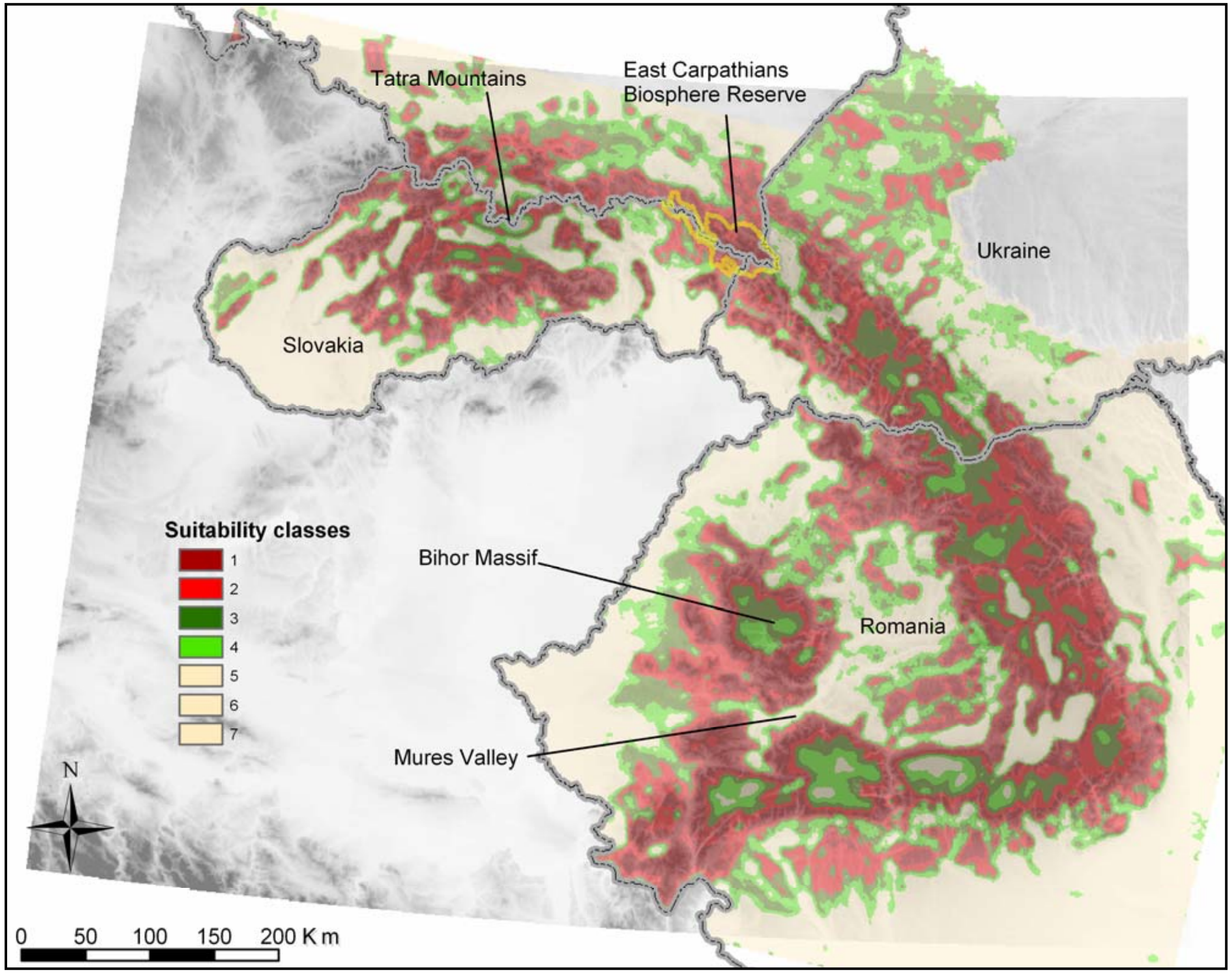


Figure 5.9 – The graphic representation of the classification output for wolf.

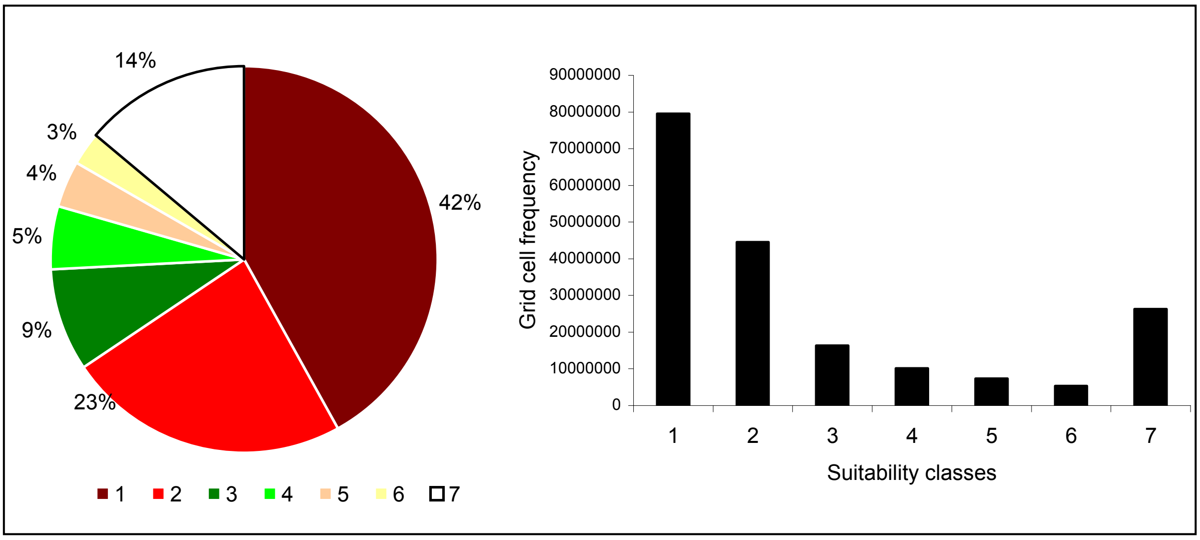


Figure 5.10 – The percentage area of the Carpathians included in the suitability classes for wolf as estimated by the Mahalanobis distance. Classes 1 to 7 indicate high to low environmental suitability.

Although continuity between Ukraine, Poland and Slovakia seems to be granted by the International Biosphere Reserve "East Carpathians", the actual situation may not be as positive as it seems because of the legal status of this emblematic species. The wolf is the carnivore that stimulates the most controversial feelings, and this is reflected in conservation practices. Environmental conservation needs to take the traditions of local communities into account, and many practices of the human communities often conflict with wolf presence. Furthermore, the wolf has the most variable local status across the Carpathians, as it ranges from being fully protected in Poland to being classified as pest species in Ukraine. In Eastern Slovakia, wolves were locally extinct in the 1970s and are now expanding back into the area from the western region of the country and the Polish Carpathians.

5.5 Output Validation

The classification of areas larger than the ones surveyed is a process that interpolates information over unknown territories, thus functioning as an estimation of reality. Considered as such, their ability to do so should always be tested before using their outputs in any application they may prove useful for.

In the present study, a classification validation was performed in order to test the classifier reliability in estimating the actual situation. This was done twice adopting two approaches and using two sets of independent data. One was derived from a sketch map delineating the extent of occurrence of the three species. This sketch map was obtained from the local experts (the same experts who provided the locations used for the training phase of the model). The other was collected by the author through an intensive field campaign in the Carpathian Mountains, interviewing local hunters and foresters.

5.5.1 Comparisons with the sketch maps of species distribution extent

The sketch map of the extent of occurrence of each of the three carnivore species considered were obtained from local researchers and wildlife managers. The data were collected by the WWF-International coordinated Carpathian Ecoregion Initiative in form of hand-drawn sketches on local country-wide maps. They were then digitised by technical staff within the Daphne Institute for Applied Ecology, in Bratislava (Slovakia), and the country maps were subsequently appended to obtain a single polygon for the whole Ecoregion. The extent of occurrence of bear, lynx and wolf extend over areas of 108,477, 110,361 and 131,315 km^2, respectively. Figure 5.11 shows the geographical representation of the sketch maps for the three carnivores.

Such sketch maps were used mainly to determine whether the current distribution as defined by the local experts would actually coincide with areas classified by the Mahalanobis distance as highly suitable for the carnivores considered.

The differences between the proportions of the Carpathian Mountains and the proportions of the extent of occurrence associated to the different classes were tested using a log-linear model for comparisons between contingency tables (Sokal and Rohlf 1995, p. 743-744). The test was performed under the hypothesis that the relative number of pixels in each class was the same in the Carpathians as a whole and in the area of occupancy of the species. This gave a measure of the tendency of the species to actively select for areas that are suitable. At the same time it was a way for testing the results obtained, as the species are expected to occupy most suitable areas. In other words, no areas of suitable environment are supposed to be empty. Thus the ability of the Mahalanobis distance to classify the majority of the area of occupancy as suitable could be interpreted as a goodness of estimation ability.

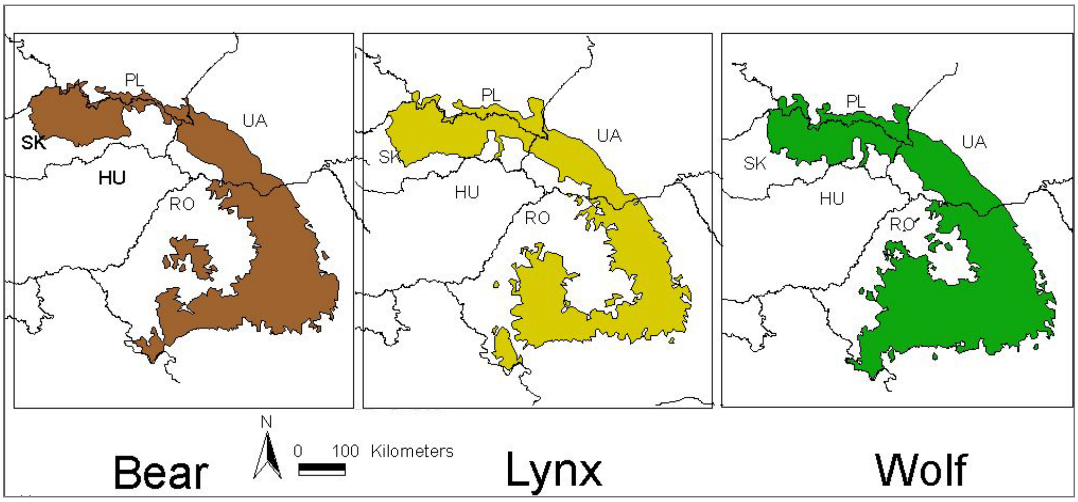


Figure 5.11 – The area of occupancy of the three large carnivores in the Carpathians, according to expert knowledge of local scientists and foresters. Kindly provided by the WWF International-coordinated Carpathian Ecoregion Initiative.

5.5.1.1 Bear

The area of occupancy of bears as defined by the local experts is distributed mainly in areas of high suitability as defined by the Mahalanobis distance, the first and second classes covering 28.9% and 31% of the sketch map range, respectively (Fig. 5.12). The least suitable class covers an area of 8,702 km^2 (8%) of the sketched presence range, and its spatial distribution is scattered among highly suitable areas of the model.

The comparisons between proportions of different classes included within the Carpathians and the extent of occurrence suggest that bears avoid not suitable regions (class 6 and 7 of the Mahalanobis distance) and that the tendency to occupy highly suitable regions (class 1 and 2) is higher than expected in the hypothesis of no difference between proportions in the whole Carpathians area and proportions within the sketch map range (fig. 5.12). The residuals of the frequency of each class within the extent of occurrence assume negative values for all classes but for the first two. They are expressed in number of cells of 250x250m of size.

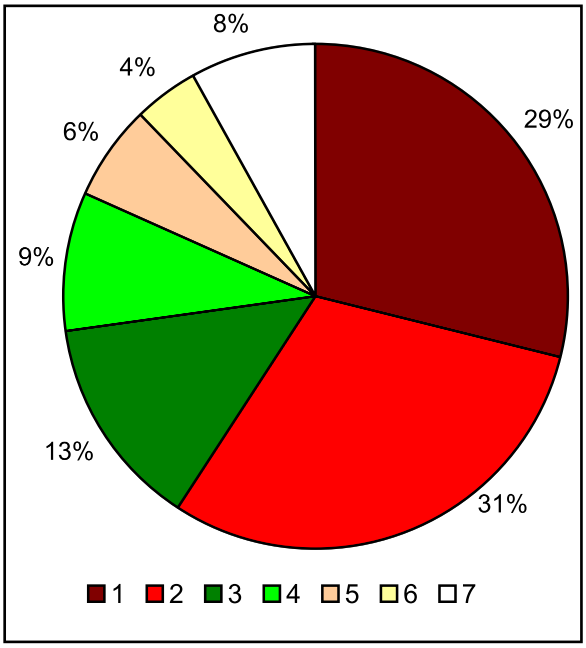
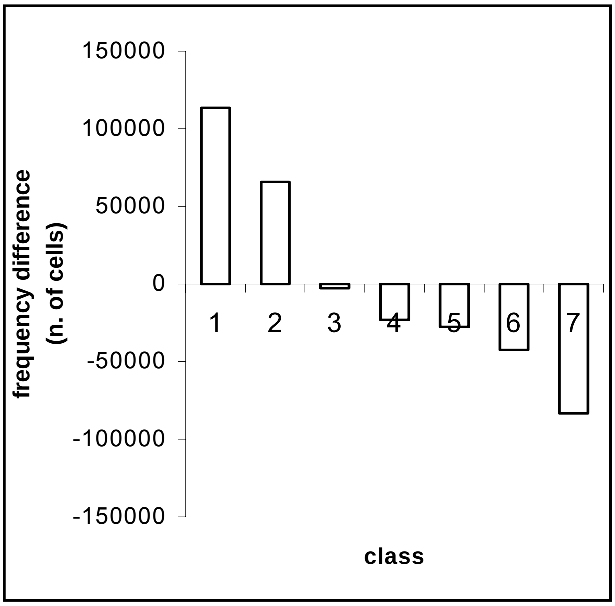


Figure 5.12 – The percentage area of the extent of occurrence of bears as defined by the experts falling within each of the classes of environmental suitability as estimated by the Mahalanobis distance. Lower graph: the residuals of each class from an expected distribution under the hypothesis of no difference between the percentage values in the Carpathians and in the extent of occurrence.



The bars represent the difference between the observed pixel frequency of each Mahalanobis distance class in the bear's extent of occurrence as defined by the local experts and the pixel frequency that would be expected if the bear occupied the Carpathians regardless of habitat suitability, and thus reflecting the same proportions of the Carpathians as estimated by the Mahalanobis distance.

This result is unexpected as, being omnivorous, bears are expected to be highly adaptable to many diverse environmental conditions. Nevertheless, it should be noted that the large range of food sources that bears feed on (Swenson *et al.* 2000) are mainly forest products, thus reflecting the dependence of bears on forested areas with low human disturbance. Furthermore, the ecological signature already explains a wide range of environmental conditions (fig. 5.6). Bears in the Carpathians have been regularly hunted until recently, and there is evidence that they are still currently hunted in the study area (Salvatori *et* *al.* 2002). This could have possibly increased the tendency of bears to avoid areas where humans are present even at low levels.

The large portion of highly suitable areas included in the bear extent of occurrence as defined by the local experts suggests the classifier performed well in estimating "good" areas for bears. No further inferences may be done at this stage, as the extent of occurrence and the model output are of different nature. Furthermore, as the source of data for training the classifier and the information about the extent of occurrence coincided (i.e., local experts), the two may be correlated.

5.5.1.2 Lynx

The majority of the lynx extent of occurrence defined by the local experts contains areas of first and second suitability classes (40 and 27%, respectively), suggesting that lynx have a tendency to occupy areas of high environmental suitability as estimated by the Mahalanobis distance. The comparison between proportions of estimated suitability classes in the Carpathians and in the lynx extent of occurrence supports such a tendency, assuming negative values for all classes but the first two (fig. 5.13).

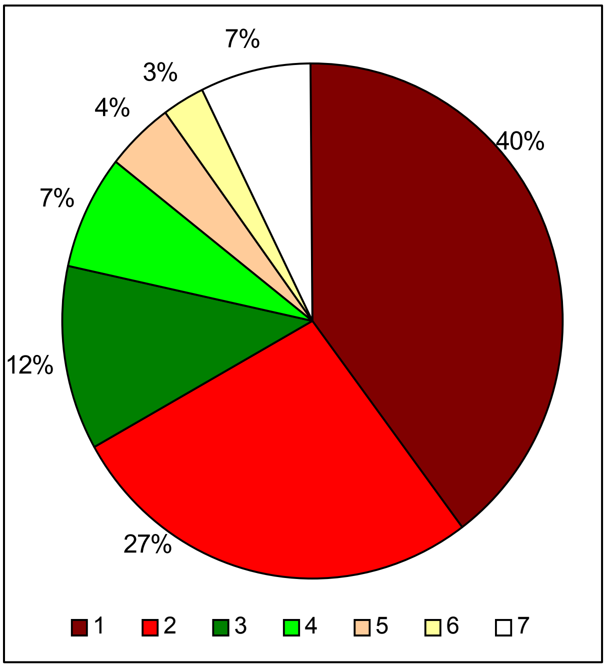


Figure 5.13 –The percentage area of the extent of occurrence of lynx as defined by the local experts falling within each of the classes of environmental suitability estimated by the Mahalanobis distance. The lower graph shows the residuals of each class from an expected distribution under the hypothesis of no difference between the percentage values in the Carpathians and in the extent of occurrence of lynx.

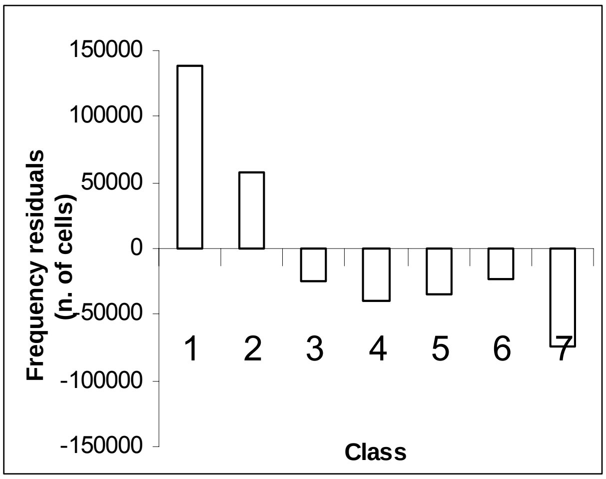


Figure 5.13 continued. – The bars represent the difference between the observed frequency of each Mahalanobis distance class in the lynx's extent of occurrence as defined by the local experts and the frequency that would be expected if the lynx occupied the Carpathians regardless of habitat suitability, and reflecting the same proportions of the Carpathians as estimated by the Mahalanobis distance.

5.5.1.3 Wolf

The majority of the wolf extent of occurrence as defined by the local experts contains most areas of first and second suitability classes (34 and 41% respectively), suggesting that wolves have a tendency to occupy areas of high environmental suitability as estimated by the Mahalanobis distance, although not strictly limited to the first suitability class.

The comparison between proportions of classes in the Carpathians and in the wolf extent of occurrence suggests such a tendency, assuming negative values for all classes but the first two (figure 5.14).

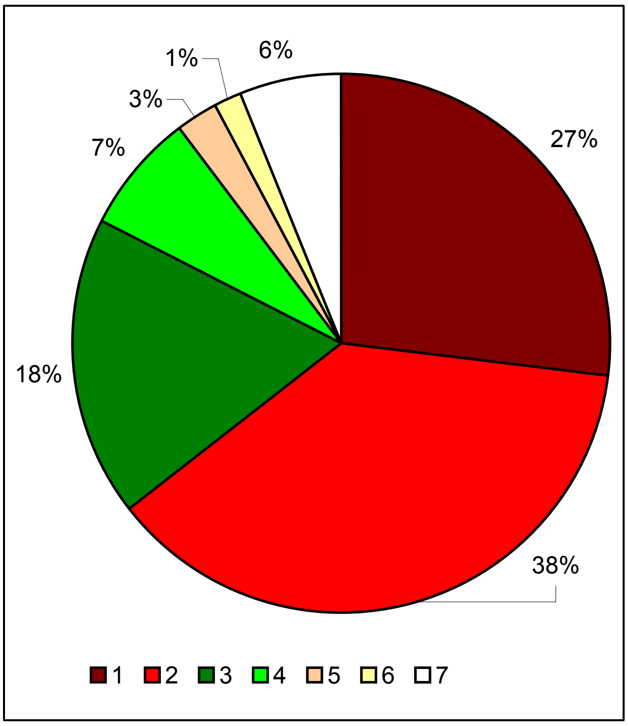
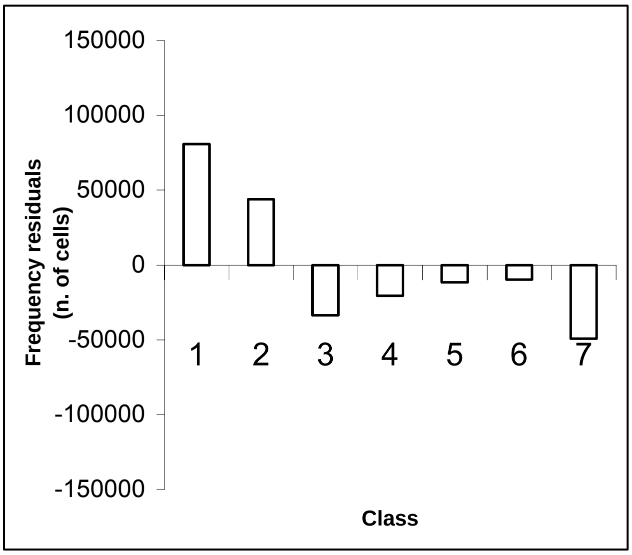


Figure 5.14 – The percentage area of the extent of occurrence of wolf as defined by the local experts falling within each of the classes of environmental suitability estimated by the Mahalanobis distance. The lower graph shows the residuals of each class from an expected distribution under the hypothesis of no difference between the percentage values in the Carpathians and in the extent of occurrence of wolf.



The bars represent the difference between the observed frequency of each Mahalanobis distance class in the wolf's extent of occurrence as defined by the local experts and the frequency that would be expected if the wolf occupied the Carpathians regardless of habitat suitability, and reflecting the same proportions of the Carpathians as estimated by the Mahalanobis distance.

5.5.2 Model Validation

A validation phase was conducted in Autumn-Winter of 2001-2002. The aim was to collect data on the presence of the three carnivores in the field. Winter was chosen in order to be able to directly sight tracks in the snow. Additionally, local foresters and hunters were interviewed about where they recently had spotted carnivores and their signs of presence.

The field campaign was supported by WWF International and approved by the Royal Geographical Society, which called it the *Carpathian Expedition*. A 4x4 Land Rover vehicle was purchased for the purpose, and the original plan was to set up a team of four people that could develop the two activities simultaneously and in a complementary manner. Unfortunately, the whole campaign needed to be re-organised at very short notice due to the unavailability of assistants, and I started the campaign with only one field assistant, arranging local contacts well before departure. In each country visited, there were local partners who travelled around the country with us, or arranged other people to do so, acting as interpreters during the interviews.

Not only the arrangements with the original team went different from what was planned, but also the weather conditions were such that late December-early January 2002 were the coldest period in the last 25 years in that area of Europe, with temperatures around 25 degrees Celsius below zero nearly every day. Because of this and the impossibility to find tracks in the exceptionally deep snow, the campaign was interrupted on the 11th of January and finally completed in April, when the snow had started melting and the temperatures were mild.

The information was collected mainly through semi-structured interviews with local experts. The selection of people was driven opportunistically by the location and the contacts the local partners had in the area. Many protected areas were visited, where interviews were held with foresters and park personnel. Also, when hunters and farmers were met by chance they were asked whether they agreed to be to be interviewed. Most of them were willing to help; they were extremely knowledgeable and enthusiastic about local wildlife. Many of the visited hunters proudly displayed their numerous trophies of both game and protected species.

A total of 61 interviews were made, and they were distributed in the four countries as follows: Slovakia = 12, Poland = 7, Ukraine = 13, and Romania = 29, yielding a total of 447 locations where carnivores' presence was recorded. These were recorded in the form of points drawn on maps at a scale suitable for the present study. In some instances the maps were recent road atlases (i.e., Slovakia and Poland) at 1: 200,000 or 1: 150,000 scale. In Ukraine a local topographic map produced by the Viskovo Topographic Firm in 1999 was available at a scale of 1:200,000, while in Romania, a printout of the regional forestry map also used for geometrically registering the locations for training the model (see section 4.3 of chapter 4) was used.

Three presence categories of carnivore' locations were recorded, depending on the character of the information given. They were:

1. track (when a track or sign of presence was reported)
2. sight (when one of the three carnivores was directly sighted)
3. den (when location of a den was identified)

The information of these three categories was only included if the sightings occurred within the last two years and not before that, in order to record only the most recent presence of carnivores. The numbers of presence locations were 124, 93 and 144 locations for bear, lynx and wolf, respectively.

The locations were used to run the Mahalanobis distance again using the same variables that were used for the estimation of suitability areas for the three carnivores. The output obtained with the validation data will be hereinafter called "reference" and will be considered to represent the reality, while those obtained with the source data obtained from the experts will be called "estimate". The reference map for each species was subsequently compared to the estimate in order to reach a measure of agreement between the estimate and the reality.

The validation procedure was performed using the VALIDATE module (Pontius 2000, 2002) within the IDRISI software (Clarks labs.). Such module compares two categorical raster images in terms of percentage of agreement between class pairs. It provides the K-statistic (Congalton *et al.* 1983) and gives measures of two components of agreement: quantity and location (Pontius 2002). The K-statistic is a measure of the difference between (a) the obtained classification agreement between two maps and (b) the agreement that would be obtained if the maps were created only by chance. The K-statistic achieves values between 0 and 1, although negative values can be assumed as well – and they suggest that the classification results are worse than any that would be obtained by chance. Values close to zero indicate that the classification performance is close to the one that would be obtained by chance (Campbell 1996, pg. 389). The two estimates of quantity and location of agreement are based on statistical procedures that use the expected agreements in the case of a complete quantity and location match; these are used for producing the statistics of $K_{location}$ and $K_{quantity}$.

5.5.2.1 Validation results

The classification output was validated with the reference classification on a per species basis, and the results were expressed in terms of agreement both on quantity of areas associated to each suitability class and on location of the areas classified as such. An analysis of fragmentation of the reference raster image was also performed in order to compare the results with the fragmentation of the classifier estimate.

5.5.2.1.1 Bear

The reference image of suitability for bear appeared to be in general agreement with the estimate image (Fig. 5.15). The validation statistics showed that agreement between the classes of the reference and estimate images was found in 65% of the area. The extent of each class were very similar between estimate and reference maps, reaching a value of $K_{quantity}$ = 0.98. A lower agreement was detected for the location of such areas ($K_{location}$ = 0.52). The overall comparison (i.e., not taking into account the location and quantity components) reached a K-statistics = 0.52. The highest $K_{location}$ value was reached for class 1 (0.6), and the lowest for classes 4-6 ($K_{location}$ = 0.11 - 0.16).

The fragmentation of the reference map was higher than that of the estimate and the first suitability class was made up of 550 patches (3.5 times the number of patches in class 1 of the estimated map) of average size 89.4 km^2 (nearly 1/3 of the average size of patches in class 1 of the estimated map), while the second suitability class was composed of 1,044 patches of mean area 46 km^2.

The spatial distribution of areas associated with different suitability degrees in the reference map is heterogeneous along the Carpathian Mountains. Although the general pattern of suitable area in the reference map follows the mountain chain as it did for the estimate, a disjunction of the highly suitable area exists throughout the region.

The areas where major disagreement is found are in Ukraine, where there is a large discontinuous area of suitable environment in the north-eastern Ukrainian Carpathians, that show no connection with the suitable areas of Poland and Slovakia.

The Eastern Carpathians are connected to the Western Carpathians only through the suitable areas in the Polish Carpathians, which become important as they represent a vital region that needs to be protected in order to avoid the isolation of suitable areas in the Slovak territory.

Of the 106 presence locations collected for bear during the validation campaign, 48 were located in areas classified as highly suitable and none were located in areas associated with the last two suitability classes of the estimate map. Table 5.2 shows the percentages of validation data that fell into the suitability classes of the estimated map.

Suitability class	1	2	3	4	5	6	7
Percentage of presence locations	45.2	31.1	13.2	7.5	3	0	0

Table 5.2 – The percentages of bear presence locations in the estimated suitability classes. Data were collected during the validation campaign.

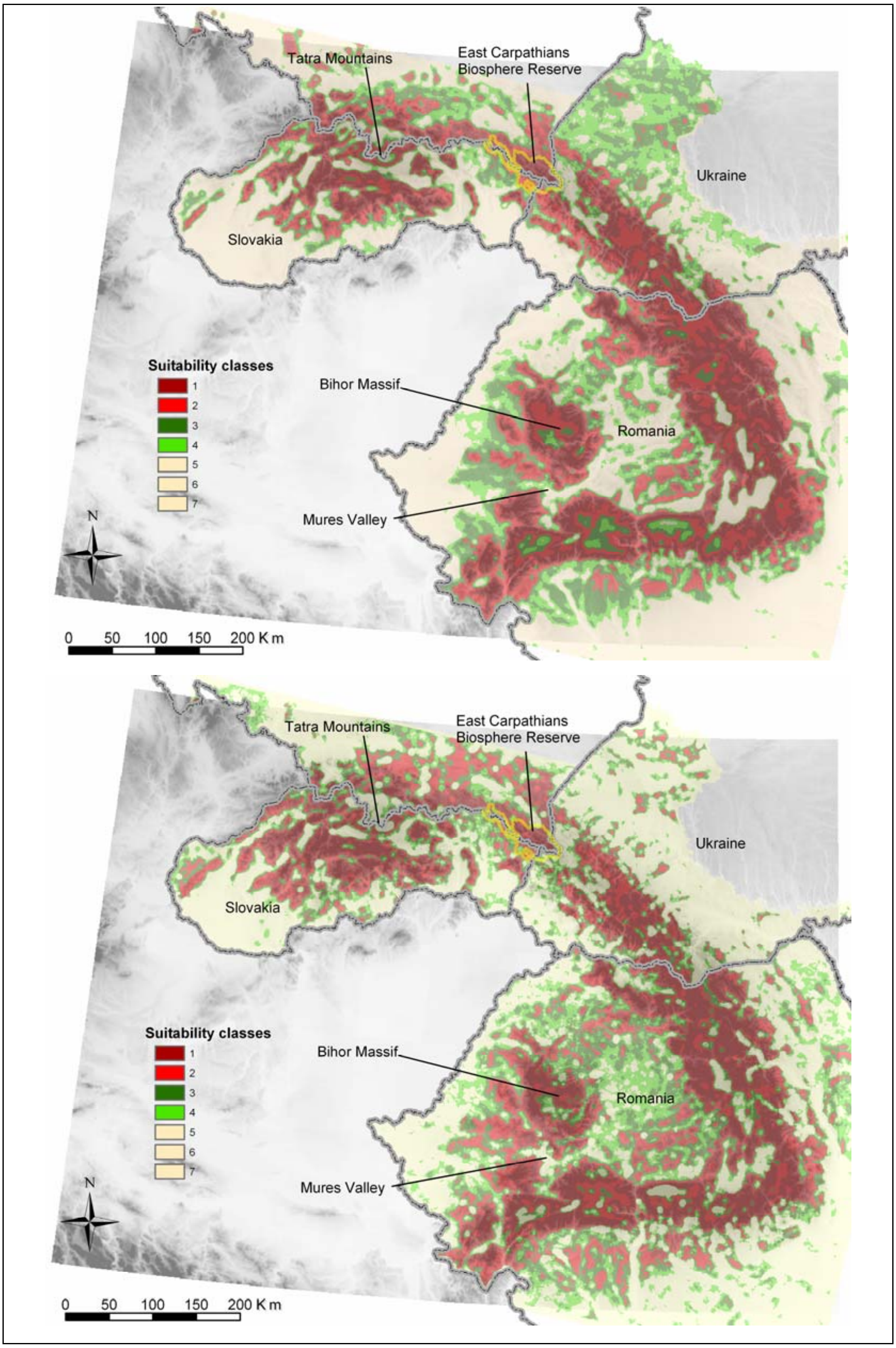


Figure 5.15 – The estimated map (upper) and the output produced with the validation data (lower) for bear.

5.5.2.1.2 Lynx

The overall agreement between the estimate map and the validation classification for lynx covered 66% of the area considered, reaching a K-statistic value of 0.53. As for the bear, the agreement in quantity of areas associated with the suitability classes was high, and the $K_{quantity}$ = 0.99, while the relative location of such areas was less consistent ($K_{location}$ = 0.53). The highest value of $K_{location}$ was obtained for the first suitability class (0.55).

Figure 5.16 shows the graphical representation of both the estimate and reference output, where the spatial distribution of areas associated with different environmental suitability can be compared. It appeared that the fragmentation of highly suitable areas for the reference map is twice as high as that of the estimate map: it is made up of 240 patches averaging 106.7 km^2 of size.

Consistently with the results for bears, the area of highest disagreement between the reference and the estimate appears to be the Ukrainian Carpathians, where large areas are classified as being unsuitable in the reference map. The discontinuity of suitable areas for lynx in the reference map appears to take place both at the Ukraine - Romania border and at the Ukraine–Poland / Ukraine–Slovakia borders. This fragmentation may potentially lead to the isolation of the Ukrainian lynx population.

The spatial pattern of distribution of the other suitability classes is consistent with the estimate map in the rest of the Carpathians. The Bihor massif appears to be separated from the southern Carpathians, as it appeared in the estimate map, while the Transylvanian plain assumes values of suitability slightly higher than the estimated ones. The Polish Carpathians appear to be more fragmented than estimated, but still potentially play a vital role in the connection between the Eastern and the Western Carpathians.

Slovakia contains a large continuous patch in the central region that is not suitable, mostly consistent with the patch of the estimated output.

The majority of lynx presence locations collected during the validation campaign were located in areas estimated initially as highly suitable, while none of them fell in areas associated with the last two suitability classes (tab. 5.3).

Suitability class	1	2	3	4	5	6	7
Percentage of presence locations	47.3	30.1	16.1	5.4	1.1	0	0

Table 5.3 – The percentages of lynx presence data collected during the validation campaign that were located in the estimated suitability classes.

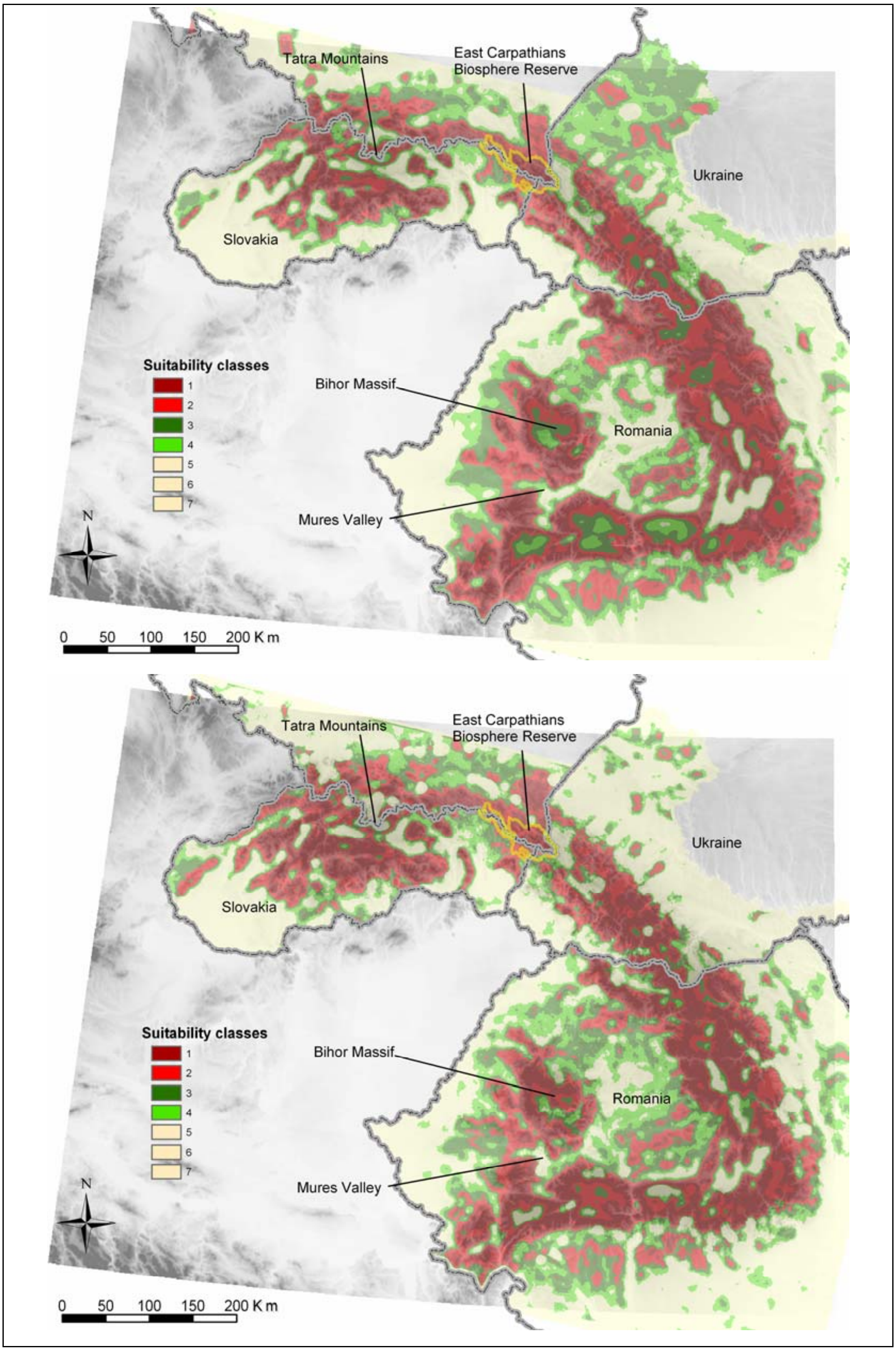


Figure 5.16 – The estimated map (upper) and the output produced with the validation data (lower) for lynx.

5.5.2.1.3 Wolf

The comparison between the estimated and the reference map of suitability for wolf detected agreement in classification over 62% of the area. The maps of the two outputs are displayed in figure 5.17. The overall K-statistic reached a value of 0.47. The agreement of location of the same suitability classes reached a $K_{location}$ = 0.48, while the agreement of quantity had a $K_{quantity}$ = 0.99.

The first suitability class was highly fragmented, being made up of 3,594 patches. This is 19.5 times as numerous as the patches that made up suitability class 1 in the estimated map. The average area of the patches is 13.6 km^2 (SD = 222.2). The second suitability class has 16,841 patches of average area 2.93 km^2 (SD = 133.5). A high level of interspersion and fragmentation is suggested by the noticeable high number of patches for all the remaining classes, which are made up of a minimum number of 1,347 (class 7).

The spatial distribution of the high suitability class is generally consistent with that in the estimated map, and the $K_{location}$ for this class is 0.43. The lowest $K_{location}$ value is relative to the medium low class 5 (0.09).

The fragmentation of suitable areas appears to be particularly high in the region near the Ukraine-Romania border. The central part of Ukrainian Carpathians shows a large patch of suitable areas that peters away towards northern areas, and disappears closer to the Ukraine–Poland / Ukraine–Slovakia borders.

The International UNESCO Biosphere Reserve “East Carpathians” appears to be of generally medium suitability according to the reference map, although the presence of wolves, at least in the Polish side of Bieszczady National Park, is reported by Smietana and Wajda (1997), Bobek *et al.* (1992) and Kanzaki and Perzanowski (1997). The Polish Carpathians are classified in the reference map with high variability, showing very small areas of medium suitability interspersed in areas of high suitability.

In the Eastern Slovak Carpathians some areas of high suitability can be found, although the continuity between the Western and Eastern portions of the Slovak Mountain system is broken in the central region, south of the Tatra Mountains area. The presence of suitable areas in the eastern Slovak region is very important in terms of wolf conservation as the region experienced a local extinction of wolves in the late 1970s. The area is presently being recolonised by wolves moving from the Polish Carpathians and the Eastern Slovak regions (Finďo pers. comm.).

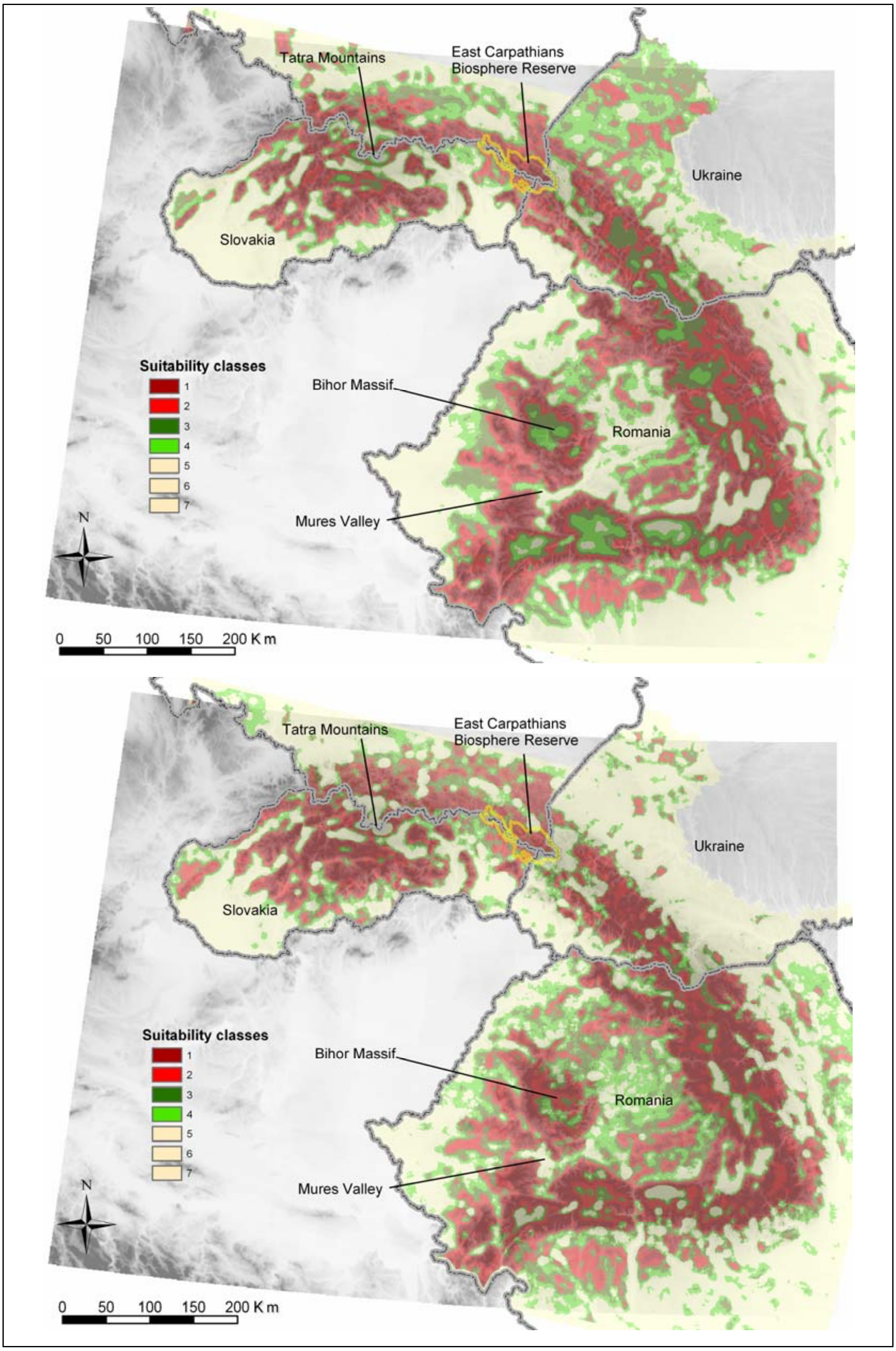


Figure 5.17 – The estimated map (upper) and the output produced with the validation data (lower) for wolf.

There was a high proportion of the validation presence locations of wolves falling within the highest suitability class of the estimated map, while none of them fell in classes 5, 6 nor 7 of the estimated map (tab. 5.4).

Suitability class	1	2	3	4	5	6	7
Percentage of presence locations	41.6	31.2	20.8	6.4	0	0	0

Table 5.4 – The percentages of wolf presence data collected during the validation campaign located in the estimated suitability classes.

5.5.3 Comparison against a deterministic model

A further validation of the classification output was performed through the comparison against the output generated through the reclassification of the land cover raster with values suggested by experts for the Italian wolf (http://www.gisbau.uniroma1.it/REN/index.htm, Boitani *et al.* 2003).

The approach is a deterministic one, ideally based on the species-habitat relationship. As it happens in most cases, the species-habitat relationship cannot be built from newly collected data because of lack of time and resources. The alternative is to consult a number of experts on the target species and ask them to assign a score to a list of habitat types according to their knowledge on the biology of the species. This was done for the project National Ecological Network of Italy, funded by the Ministry of Environment and developed by the University of Rome (Boitani *et al.* 2003).

The analytical approach is a deductive one, because the starting point is the assumption that basic knowledge on the species is available and thus we are able to establish a degree of suitability for each of the habitat considered. The species-habitat relationship is thus built on the basis of expert knowledge coming from scientists who have a long-term working experience with the target species.

The Italian National Ecological Network project built species-habitat relationships for 477 vertebrate species, contacting experts for each species. The experts were given a table reporting all the land cover classes present in the CORINE Land Cover data base, and were requested to assign a score between 0 and 3 to each of them according to the suitability of such class for the presence of the species. The classes represent the following rank of suitability:

0 → Class not suitable for the presence of the species;

1 → Class characterised by the partial presence of resources necessary for the species;

2 → Class characterised by the presence of the resources necessary for the presence of the species but not at optimum level;

3 → Class characterised by the presence of the resources necessary for the presence of the species at optimum level.

Such an approach could not be used here because of the lack of exhaustive data on the ecology of the species collected through scientific research.

The table produced for the wolf in Italy was used here to reclassify the land cover raster of the Carpathians in order to check for consistency with the outputs generated with the Mahalanobis distance. Although the ecological conditions of the Carpathians are somehow different from those of the Italian peninsula, there are some similarities that make the comparison meaningful. For example, the Italian peninsula is crossed all the way through in the N-S direction by the Apennine Mountains, a chain that shows altitudinal characteristics similar to the Carpathians. The continuity through a long part of land is also a similarity. The presence of a strong agricultural economy and of large forested areas of *Fagus spp*. and *Quercus spp*., as well as the lack of large urban areas make the Apennines very similar to the Carpathians. There is a population of around 500 wolves living in peninsular Italy, for an extension of 160,000 km^2 ca. Table 5.5 reports the scores associated to the Corine Land Cover classes for Italy, and fig. 5.18 shows the outputs generated by the reclassification operation and the residuals with the outputs of the Mahalanobis distance.

Table 5.5 – The scores associated to the CORINE Land cover classes as given by the expert prof. L. Boitani for the Italian wolf (modified after Boitani et al. 2002).

CORINE Class	Score
Continuous urban fabric	0
Discontinuous urban fabric	0
Industrial or commercial units	0
Road and rail networks and associated land	0
Port areas	0
Airports	0
Mineral extraction sites	0
Dump sites	1
Construction sites	0
Green urban areas	0
Sport and leisure facilities	0
Non-irrigated arable land	0
Permanently irrigated land	0
Rice fields	0
Vineyards	0
Fruit trees and berry plantations	1
Olive groves	0
Pastures	2
Annual crops associated with permanent crops	0
Complex cultivation patterns	0
Land principally occupied by agriculture, with significant areas of natural vegetation	1

CORINE Class	Score
Agro-forestry areas	2
Broad-leaved forest	3
Coniferous forest	3
Mixed forest	3
Natural grassland	2
Moors and heathland	2
Sclerophyllous vegetation	1
Transitional woodland-scrub	2
Beaches, dunes, sands	0
Bare rocks	0
Sparsely vegetated areas	1
Burnt areas	2
Glaciers and perpetual snow	0
Inland marshes	0
Peat bogs	0
Salt marshes	0
Salines	0
Intertidal flats	0
Water courses	0
Water bodies	0

Comparing the scores of the land cover classes with the grouping previously done for the variables to input into the Mahalanobis distance classifier (see section 4.3.1 in chapter 4), it appears that most of the groups generated through the reclassification of the CORINE land cover into seven classes are associated to a unique score, suggesting the groups are consistent to the scores given by the expert. Table 5.6 shows how many classes in each group were associated to each score.

Group	Name	0	1	2	3	Total n. classes
1	Forest			1	3	4
2	Grassland		1	4		5
3	Agriculture	7	3	1		11
4	Water	7				7
5	Urban areas	9	1			10
6	Roads	1				1
7	Barren land	3				3

Table 5.6 – The number of classes included in each land cover group generated in the pre-processing phase of data to be used for the Mahalanobis distance (see fig. 4.1 in chap. 4).

In order to compare the outputs generated by the Mahalanobis distance and the classification according to the scores given by the expert, the former needed to be reclassified in order to produce four suitability classes instead of seven (see section 5.3 above). The reclassification was made following the criteria such that:

Class 0 → Not Suitable, i.e. those environments that do not satisfy the ecological requirements of the species;

Class 1 → Low Suitability, i.e. those environments that may support the presence of the species but in an instable way through time;

Class 2 → Medium Suitability, i.e., those environments that support the stable presence of the species but not represent the optimal habitat;

Class 3 → High Suitability, i.e., those environments that represents the optimum for the species.

The seven classes were thus grouped as follows:

1,2 → 3

3,4 → 2

5 →1

6,7 →0

The comparison of the two rasters resulted in a consistency of 47.8% between the two. Particularly, the classes 0 and 3 were highly consistent, while the middle classes had the highest values of omission and commission (tab. 5.7).

	0_{MD}	1_{MD}	2_{MD}	3_{MD}	Tot_{MD}
0_{ES}	**1195454**	397491	373497	135980	2102422
1_{ES}	120906	**139117**	367356	192104	819483
2_{ES}	77755	84860	**198715**	235294	596624
3_{ES}	86402	138180	605506	**1052571**	1882659
Tot_{ES}	1480517	759648	1545074	1615949	5401188

Table 5.7 – The error matrix of the classifications obtained by the expert score method (ES, rows) and the Mahalanobis distance (MD,columns). Figures report number of cells.

The graphic representation of the output generated using the reclassification method and a map of the absolute of the residuals are shown in fig. 5.18.

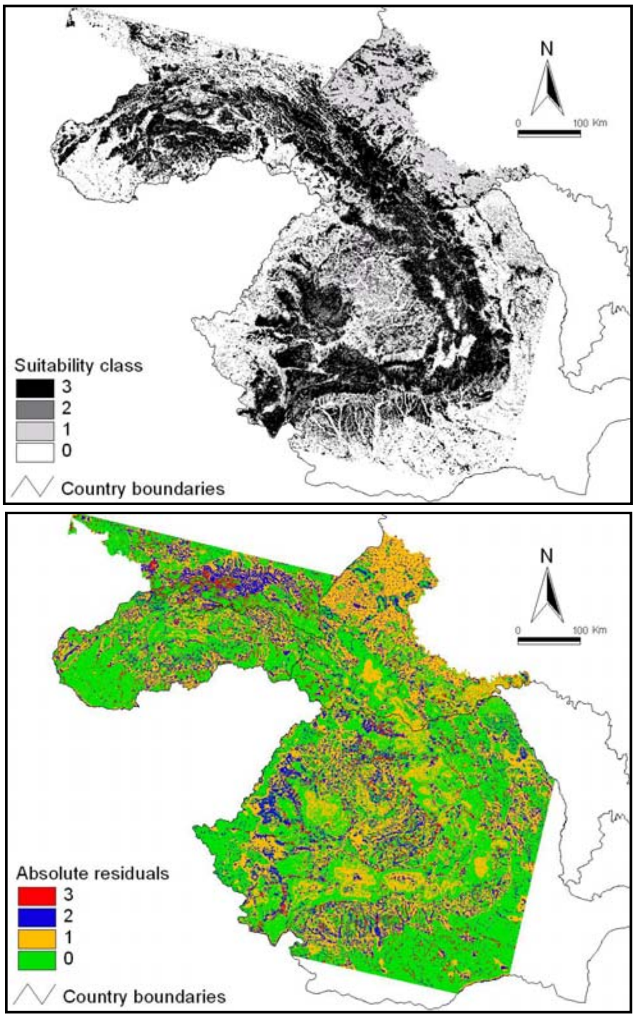


Figure 5.18 – The suitability map resulting from the reclassification of the land cover classes according to the scores given by the expert for Italian wolves (left) and the map of residuals (right) between it and the one resulting from the Mahalanobis distance classifier (see fig. 5.9 and section 5.4.3).

A graph of the percentages of each class produced from the score method contained in each of the classes produced by the of the Mahalanobis distance classifier is shown in figure 5.19.

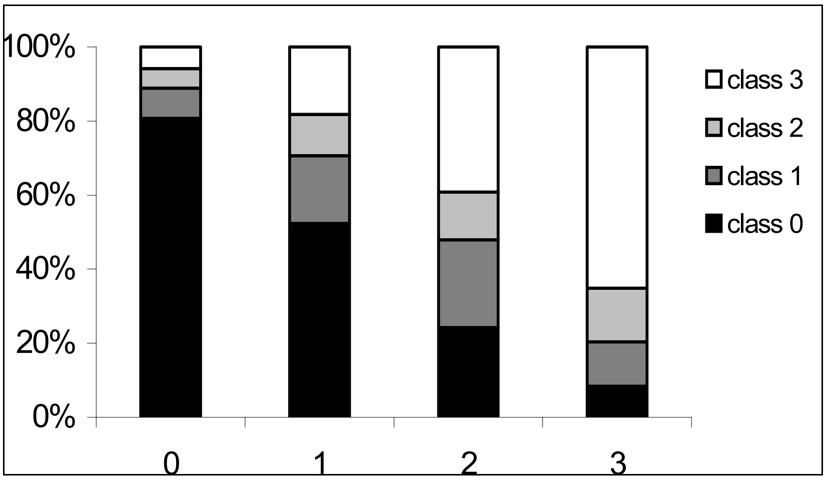


Figure 5.19 – The proportions of each suitability class of the map obtained with the Mahalanobis distance method contained in each class of the map obtained through the reclassification of land cover with scores obtained by the European expert on wolves.

An extremely important difference between the two methods is the inclusion of the concept of spatial scale at which the environment is perceived by the three carnivores, i.e., the home range size. The deterministic model does not take into account the effect of the surroundings may have on a specific location. It only considers parcels of specific habitat as defined by humans while classifying information on the land. This is certainly a limitation that the map algebra operations in the approach used throughout this project were aimed at overcoming. Through ignoring the spatial scale at which the target species perceive the environment leads to the classification of suitable areas in a matrix of unsuitable environment, thus they may be unsuitable for their limitation in size or for the presence of surrounding unsuitable areas. In order to show the advantage that the inclusion of the home range size smoothing window brings into the process, fig. 5.20 reports a detail of the graphic representation of the outputs generated by the deterministic model and the Mahalanobis distance over a sample subset of the study area.

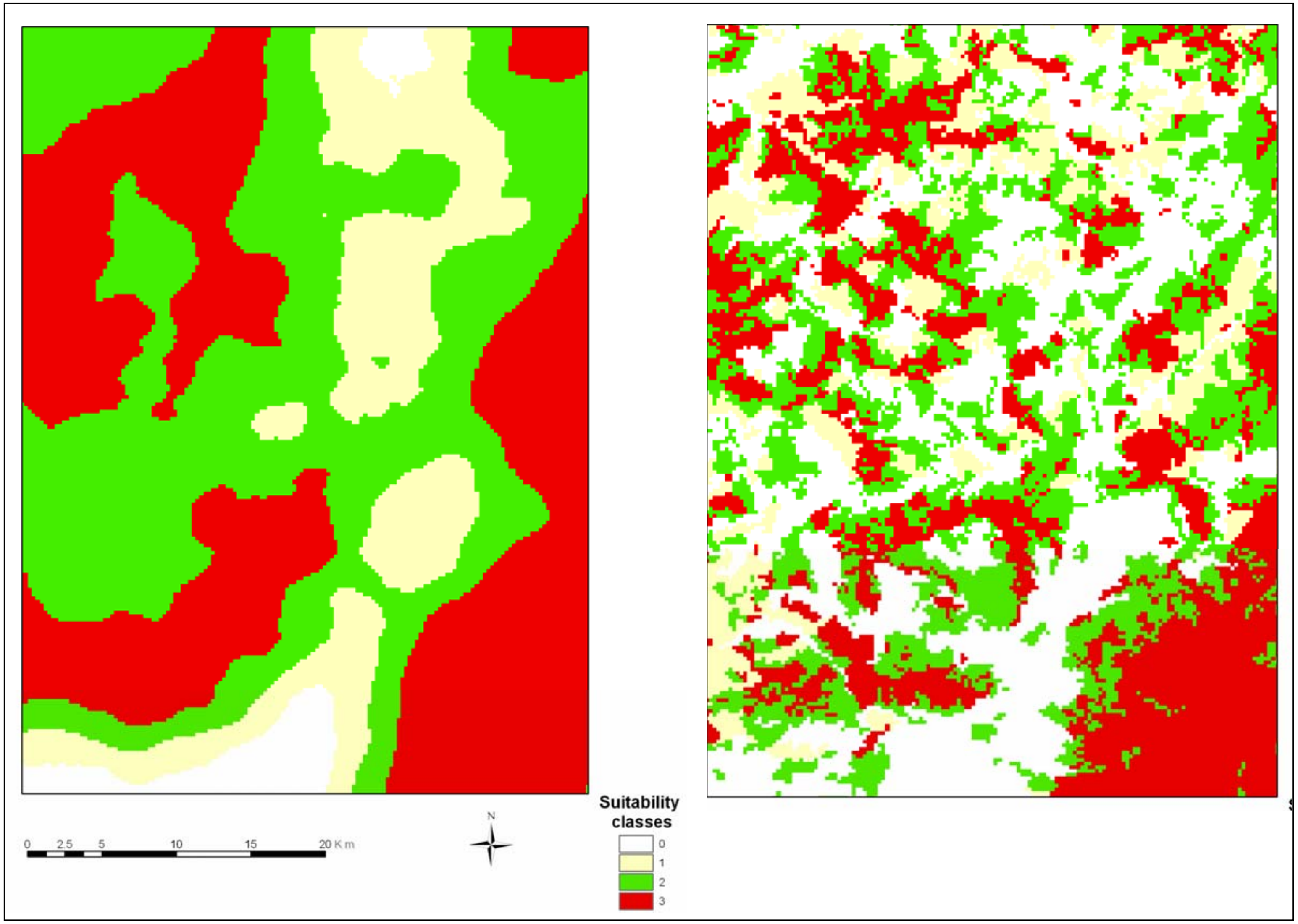


Figure 5.20 – The outputs produced by the Mahalanobis Distance (MD, left) and the Expert Score method (ES, right) over a subset of the study area.

5.6 The Multi-species Approach[1]

The environmental suitability estimation is critical for conservation purposes, and in order to maximise efforts and efficiently use the limited resources available, the information gathered should be used for obtaining the best possible effects out of only few conservation actions.

The results of the models for each of the three carnivores were then pooled together in order to obtain one single model to estimate the overall suitability for all large carnivores. This was particularly appropriate in the present study, as the results obtained for each species were very similar. Furthermore, the countries involved in any possible conservation action have very limited resources and the optimisation of effort, hoping that one action may benefit three species at once, is strongly desired. The integration of results coming from the three species separately was requested by the Council of Europe in order to fulfil the Ecological Network objective of the Natura 2000 programme included in the EU Habitat Directive.

The pooling of results was performed by intersecting the three raster maps using the minimum function. This function is generally used for fuzzy sets, and it was considered to be appropriate for the purpose of combining the three outputs of the Mahalanobis distance, which are not probability values, hence probability calculus would not have been appropriate (Hill and Binford 2002). With the minimum function, the raster images are pooled together in a conservative manner so that each cell is assigned the worse case value selected from the three suitability maps. For example, in the case of likelihood of carnivore presence, or forecasted density, the output grid would have cells with the lowest value occurring in any of the raster images to be pooled. In the present case, the Mahalanobis distance associates small values with more suitable environmental conditions; hence the conservative minimum function assigns the highest Mahalanobis distance of the available ones in the three carnivore outputs to the combined suitability map. In other words, the suitability minimum function is a Mahalanobis distance maximum function.

Figure 5.21 gives an example of what would result from the union of three hypothetical raster images of 3x3 cells containing values of the Mahalanobis distance.

[1] Part of this section is published as Salvatori (2002).

1	1	1		2	1	1		1	2	1		2	2	1
1	2	2	and	1	1	2	and	1	2	1	=	1	2	2
1	3	2		2	3	3		3	3	3		3	3	3

Figure 5.21 – The resulting grid from the minimum function operation for the intersection of three grids containing D^2 values would contain the highest value assumed by any corresponding cell of the three input images.

The output grids of both the estimated and the reference suitability map represented as the Mahalanobis distance (D^2) for the three carnivores were pooled together and compared for validation purposes. The two-pooled maps are displayed in figure 5.22.

The output estimate map for the three carnivores' suitability was consistent with the results obtained for the three species separately. The conservative character of the minimum function is reflected in the low portion of the Carpathians classified as the first class of suitability. This class accounts only for 8% of the total study area. The geographic distribution of the areas of highest suitability is composed of 169 patches of 171.2 Km^2 of average extent (SD = 496). Class 7 was made up of 414 patches, showing that the number of patches increased with increasing D^2 values. The largest average patch area was found in class 2 (278 patches, 14.7% of the area), with a mean size of 180.3 km^2, second in patch size came class 1. The standard deviation of class 2 (2,153.6) suggests there is a high variability in its patch size.

The reference map for the three carnivores' suitability shows a different pattern to that of the estimate, the first suitability class covering a larger portion of the Carpathians (10%), and being made up of a large number of patches (1,426) of smaller mean size (23.8, SD = 239 km^2) than the ones in the estimated map. The second suitability class covers 13% of the whole region, and has 7,382 patches of 60 km^2 mean size (SD = 165).

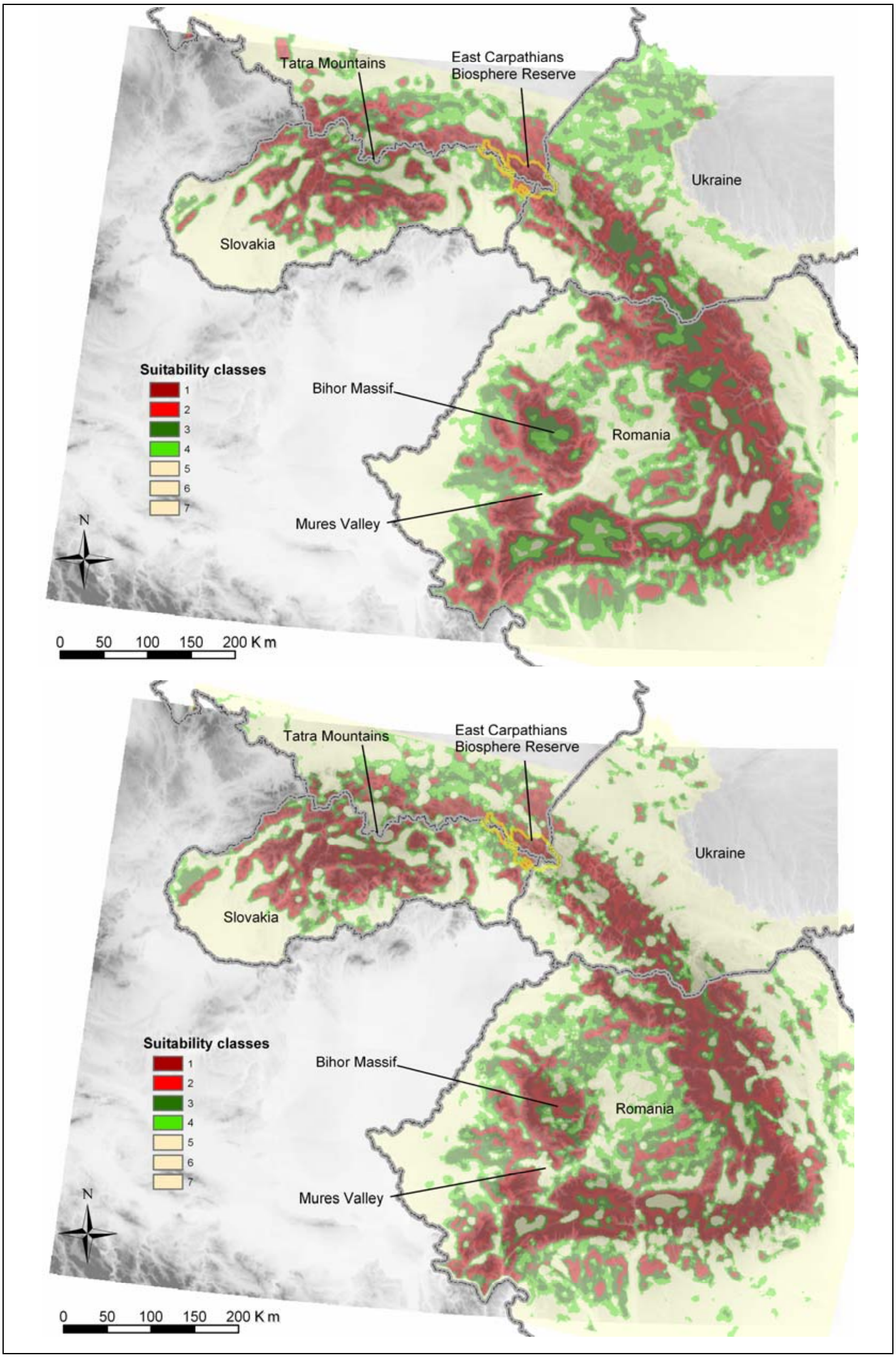


Figure 5.22 – The resulting raster images from the union of the three estimated and reference raster images of the D^2 values.

The comparison between the two combined outputs showed that 64% of the area was assigned to the same classes both in the estimated and the reference rasters. The validation procedure yielded a K-statistic = 0.5, with the $K_{location}$ = 0.53 and $K_{quantity}$ = 0.94. Class 1 yielded the highest values of $K_{location}$ (0.42), while the lowest was assigned to class 6 (0.16).

The geographical distribution of the areas associated to the highest suitability class follows the pattern of the mountain arc, covering elongated areas around patches of class 2 in the estimate map, while in the reference map they assume a more continuous patchy patterns along the mountains, with larger areas interrupted by very small areas of class 2, with which class 1 is highly interspersed.

5.7 Discussion

It is important to consider that the Mahalanobis distance allows for the establishment of a **functional** relationship between the species' presence and the environmental variables considered within the study area, and not a **causative** relationship. The approach, in other words, does not explain *why* the carnivores are at the locations where their presence was recorded. When the wildlife-habitat relationships were described (see section 2.4 in chapter 2), the emphasis was on the description of the correlation between the species' presence and the environmental variables. An approach defining the causative relationship might require local studies, on well-studied species, and with enough data that could statistically support the definition of a correlation function. In the present study, however, it was not possible to establish causative relationship with the available data. In order to develop a model that would describe the causative relationships between the species and the environment they inhabit, much more detailed and site-specific studies are needed.

Nevertheless, the approach describing a functional relationship offers the great advantage of working with only presence data and not requiring variables to be uncorrelated. The inductive approach adopted here is therefore valuable in cases when the area of interest has an extent such as that of the Carpathian Ecoregion and the paucity of available behavioural studies about the target species forces the analyst to use indirect measures as training data.

The limitation of the Mahalanobis distance classifier is that it considers the *mean* value of environmental variables at the training location as optimal. The mean value is only representative of the data if the distribution of the considered variables is normal. Although this condition is rarely satisfied in environmental data, in the present study the assumption was made that the mean represented the suitability of the environment regardless of the actual distribution of data.

There are a number of considerations that should be made when interpreting the outputs produced by the Mahalanobis distance classifier. They are related to: (1) the nature of the Mahalanobis distance estimator, (2) the nature of the training data, and (3) the process of slicing the output and produce discrete classes. These three issues are interrelated and will be discussed below.

Firstly, the Mahalanobis distance is a measure of similarity. It assigns scores of dissimilarity of vectors to a reference vector. In the present study it was applied to determine the dissimilarity of any environmental vector to a vector assumed to represent the optimal environmental conditions for large carnivores. This assumption of optimality is difficult to support with wildlife data. Secondly, since the target species spend most of their time away from human observation, it is extremely difficult to determine which are the environmental conditions they actually prefer without a radiotelemetric study, and therefore estimation of such preferences are strongly affected by the quality of available data. The presence locations provided by the local experts and used for training the Mahalanobis distance classifier may describe only areas where the animals were just passing by, and that are not actually their “preferred” places. These preferred places may be areas that are hard to access by humans, so that they are not included in any of the reports by local expert or hunter. This may lead to a misestimation of such inaccessible or rarely visited places, classifying them not as suitable as they are in reality (in some cases they may be even more suitable than where the species were reported to be present, Knick 1998). In this particular application of the Mahalanobis distance, it is suspected that there is a higher risk that presence data are not representative of the truth for the Ukrainian sector of the Carpathians, because of less active research and fewer hunters and foresters roaming in the area. This may also explain the fact, as noted earlier, that the Ukraine results do seem anomalous.

The Polish and Slovak collaborators, on the other hand, are actively involved in radio-tracking studies with at least one of the carnivores, they have ample opportunity to roam in the local part of the Carpathians and they are used to recognising tracks and signs of presence of the three carnivores, thus reporting up-to-date information. The data for Romania came from the annual census of the hunted species that the managers of the hunting grounds are required to carry out by law. Although the animal population numbers produced may not be accurate, due to errors introduced by double counting of animals roaming across large areas, the absolute animal population was not as relevant for this study as information about where animals prefer to be. Therefore, the data used here were extracted from such censuses considering that, for example, areas where a minimum of five lynx were counted meant that at least one lynx was present and that the area could be considered as suitable for the lynx.

The presence data for Ukraine were provided by local researchers as shown in fig. 4.8 (see chapter 4). It was not possible to determine the quality of the data received. Resources for wildlife managers and researchers are extremely limited in Ukraine. Therefore, the Ukrainian training data are potentially a source of error when estimating the suitability signature of the reference data.

The third issue to be considered when using the Mahalanobis distance estimator is that it produces output of continuous values of increasing distance from the signature vector. Such values need to be converted into discrete classes in order to be easily presented and compared. The criteria for producing discrete classes are highly subjective and different class thresholds may lead to different proportions of area covered by each class. However, the approach adopted in the present study standardises the procedure, using distribution parameters for setting the thresholds. The distribution of the environmental attributes measured at all training locations in both the estimate and the reference maps did not satisfy the conditions for being considered to follow a gaussian distribution. For this reason, the mean and standard deviation were replaced by the median and the upper quartile values in all cases. In spite of the objectivity of such method, the thresholding process strongly affects the outputs of the Mahalanobis distance expressed as discrete classes, and caution should be taken when using such data in a rigorous manner for management purposes.

The inclusion of large proportions of highly suitable areas within the extent of occurrence as defined by the local experts for all of the three carnivores suggests that the model has performed well in its definition of areas potentially suitable for each species. However, these results cannot be taken as a proper validation, because the maps of the extent of occurrence were drawn by the same experts that provided the data used for training the model, thus the two data are not independent, the results are encouraging in the classification ability of the model.

It is noticeable that, although the differences between frequencies of each class in the extent of occurrence and those expected under the assumption of equal frequency between the Carpathians and the extent of occurrence are significant for the three species (Pearson's χ^2, $p < 0.001$ always), the residuals of the first two classes for wolf (class 1: 80,757; class 2: 43,893) are smaller than for lynx (class 1: 139,105; class 2: 57,121) and bear (class 1: 113,500; class 2: 65,793). This not only reflects the patterns of the classification of the whole Carpathian region (whereby the area of class 2 is greater for wolf than for the other two species, and class 1 is greater than the one for bear and equal to the one of lynx), but also suggests the generalist character of wolf. Wolves are highly adaptable and they may inhabit areas that are extremely variable, thus allowing for a larger variance in the ecological signature that may not differ strongly from many areas in the Carpathians.

When considering the per-class values of $K_{location}$ with the proportions of presence locations falling in the estimated suitability classes it can be deduced that the low value of $K_{location}$ may be caused by a higher fragmentation of the reference map than that of the estimate and therefore, small areas of one class value may be interspersed in larger areas of a different class. Considering that the $K_{location}$ statistic is derived by a comparison on a per pixel basis, the low kappa value could be explained by the large number of isolated (or nearly so) pixels included in areas of other classes.

As for the location of the validation presence points are concerned, there appears to be only a low consistency in the Ukrainian portion of the Carpathians, where visited areas were not uniformly dispersed across the Ukrainian mountain range. This results may be a further support of the hypothesis that the quality of data obtained from Ukraine and used for training the Mahalanobis distance classifier were of poor quality.

The low value of $K_{location}$ may suggest a poor performance of the classifier. However, the high proportions of validation point locations in highly suitable areas suggest the Mahalanobis distance performs well. In fact, a visual comparison of the estimated and reference maps shows that the general distribution patterns are consistent. At the spatial scale considered, and taking into account the lack of baseline data available for the area, the estimated output may be considered an accurate enough representation of the real situation.

Having considered all the potential problems and technical weaknesses of the method used, the outputs produced and the ecoregional approach adopted are of high ecological value. The consideration of the Carpathians as a unit, and thus the carnivores' population across the international boundaries, is of vital importance for the conservation of such population and the European population of carnivores as well. In fact, the Carpathian populations of bear, lynx and wolf represent a large portion of the European ones (Boitani 2000, Breitenmoser *et al.* 2000, Swenson *et al.* 2000). It is at the spatial scale considered in the present study that the ecosystem studies are currently developed and it is that scale that is needed to understand the dynamics of the ecosystems the carnivores are important part of. The spatial scale at which the analyses were carried out in the present study is consistent with those used in other regional studies on biodiversity conservation (Groot Bruinderink *et al.* 2003, Boitani *et al*. 2002, Støbet-Lande *et al.* 2003), focusing on biogeographical units that call for an interregional effort in order to conserve species that cannot be maintained through local, isolated actions (Olson and Dinerstein 1997). European biodiversity is highly fragmented and the consideration of regions that host high portion of such biodiversity should be of primary importance. The present study represents one aspect of the basis for a development process that will be undertaken by the accession countries entering the EU, thus providing valuable information about the geographical distribution of areas potentially under threat for conservation of European biodiversity. The recognition of the importance that the Carpathians have in European biodiversity has brought the governments of Czech Republic, Hungary, Poland, Ukraine, Romania and Serbia and Montenegro to sign the Carpathian Convention in Kiev (UNEP 2003), whereby the adhering countries are committed to '…take appropriate measures to ensure a high level of protection and sustainable use of natural and semi-natural habitats, their continuity and connectivity, and species of flora and fauna being characteristic to the Carpathians, in particular the protection of endangered species, endemic species and large carnivores.' (Art. 4.1) and to '…cooperate in developing an ecological network in the Carpathians, as a constituent part of the Pan-European Ecological Network, in establishing and supporting a Carpathian Network of Protected Areas, as well as enhance conservation and sustainable management in the areas outside of protected areas.' (Art. 4.5). It is noticeable that when pooling the three species, 23% of the Carpathians were highly suitable (class 1 and 2), while in the Alps, a similar analysis showed that only the 7.5% of the area is highly suitable for the same three species (IEA 1999), thus emphasising the importance that the Carpathian Mountains have in the European environment.

In this context, as protecting the land and the species are two of the actions that conservationists and managers can pursue for the maintenance of large carnivores in Europe (see chapt. 1), the role of protected areas in the

Carpathian Ecoregion appears to be extremely interesting, and the consistency between their location and the geographical distribution of areas suitable for the large carnivores in the region will be explored in chapter 8, where the implications of the results obtained here on the management of large carnivores in the Carpathians will be considered.

5.8 Conclusions

The suitability of the environment for large carnivores across a whole ecoregion – the Carpathian Mountains – was mapped with a similarity estimator, which uses the multivariate Mahalanobis distance, from a reference set of optimum environmental conditions. The method adopted here has advantages over other methods that made it possible to work with limited and inconsistent input data – a situation currently faced by most animal ecologists. The output produced showed that the Carpathians have a high proportion of their territory that is suitable for the three European large carnivores. Species-specific map predictions indicated that a consistent pattern exists and the comparison with expert knowledge on their extent of occurrence indicated that the estimated highly suitable class accurately predicts the preferred habitat of all three carnivores.

The multi-species approach delineated the areas where the effort should be maximised for the conservation of all three species at once. High suitability classes were less sizeable in the pooled results, revealing a differentiation in environmental preference, which leads to minimisation of inter-specific competition between the three species. The second suitability class had a large overlap for the three carnivores.

Model validation was performed both through comparison with each species' extent of occurrence, as predicted by experienced local ecologists, and using newly-collected and independent presence data. Validation results show that the Mahalanobis distance classifier is able to produce results that are consistent with the real situation.

A final comment is that the results obtained are only appropriate at the resolution they were produced. In this study the scale was international and the Carpathians considered as a unit crossing international boundaries was considered. The author predicts that the Mahalanobis distance classifier can also be applied to study management solutions at local scales, but then it should also be applied to environmental data of finer resolution and fed with locally detailed data.

In order to test the performance of the classifying approach at different spatial resolutions, the results obtained using data at three different spatial resolutions will be compared in chapter 6.

6. COMPARISON ACROSS SPATIAL RESOLUTIONS

6.1 Introduction

The study of processes that take place over large areas should consider the whole extent where they are present in order to identify all the factors that regulate them. In the context of the present study, this would coincide with the boundaries of the Carpathian Ecoregion. The main reason for considering the whole Carpathian Ecoregion as a unit that would contain a sub-population of large carnivores within the fragmented European landscape is that the process considered here, i.e. the distribution of a large carnivore population, seems to be continuous over the whole region and it represents a major portion of the European large carnivore population.

The extent over which processes of interest take place is only one aspect of the spatial scale, and there are other aspects that are important to consider. They are (1) the spatial resolution at which target organisms are affected by local environmental conditions, and (2) the spatial resolution at which the environment variables may be measured (Aspinall 2001). The former was defined in the present study as the specie's perception of space, and will be maintained constant throughout the analytical processes. The latter may have an influence on the performance of the adopted method for classification of environmental suitability.

The effect of spatial resolution of the variables used was investigated under the hypothesis that the results of the suitability classification would not change when changing the spatial scale of input data. The hypothesis was supported by the fact that although the information on environmental conditions may be much more detailed at finer spatial resolutions, the target species won't be affected by the increased detail, as their perception of space is larger that the coarsest spatial resolution considered. A significant difference between outputs may have an influence on the management decisions to be made for the conservation of large carnivores.

The spatial resolutions considered for input variables were 1km and 30m, to be compared with the output presented in the previous chapter, at 250m resolution. They were selected following availability of digital data on land cover

over the area and spatial resolution of unprocessed satellite images produced by the ETM + sensor on board the Landsat 7 satellite.

Section 6.2 will describe the steps undergone for preparing the data to produce the outputs, which will be presented in section 6.3. The results of the comparisons will be presented and discussed in section 6.4.

6.2 Data pre-processing

The perception of space of the three species, represented by averaging the variables using a window of the size of the species' home range, was kept constant. The map algebra operations explained in section 4.4 of chapter four, were always run according to the estimates of territory size (59.9, 139.3 and 82 km^2 for bear, lynx and wolf, respectively). In this way, the major differences expected were dependent only on the details contained in the input environmental variables.

The outputs obtained with the Mahalanobis distance run with input variables coming from land cover at 250m, 1.1km and 30m resolutions were in the format of continuous values of increasing distance, thus they needed to be reclassified. The comparisons between them were performed under the hypothesis of no significant difference because the perception of space of each species is larger that the smallest picture element of the input variables of the models. For ease of calculations and for the appropriateness of use of data at 30m resolution, the comparisons were performed only over an area of 58x68 km of extension, over the Southern Romanian Carpathians (Fig. 6.1).

The choice of such area was driven by the presence of local partners who provided data on large carnivore presence at appropriate resolution, coming from field radio-tracking activities, (CLCP 2002) for further analyses. The area is characterised by the presence of the newly established (1992) Piatra Craiului National Park, the Bucegi Mountain Massif south West of the Regional Capital city Braşov.

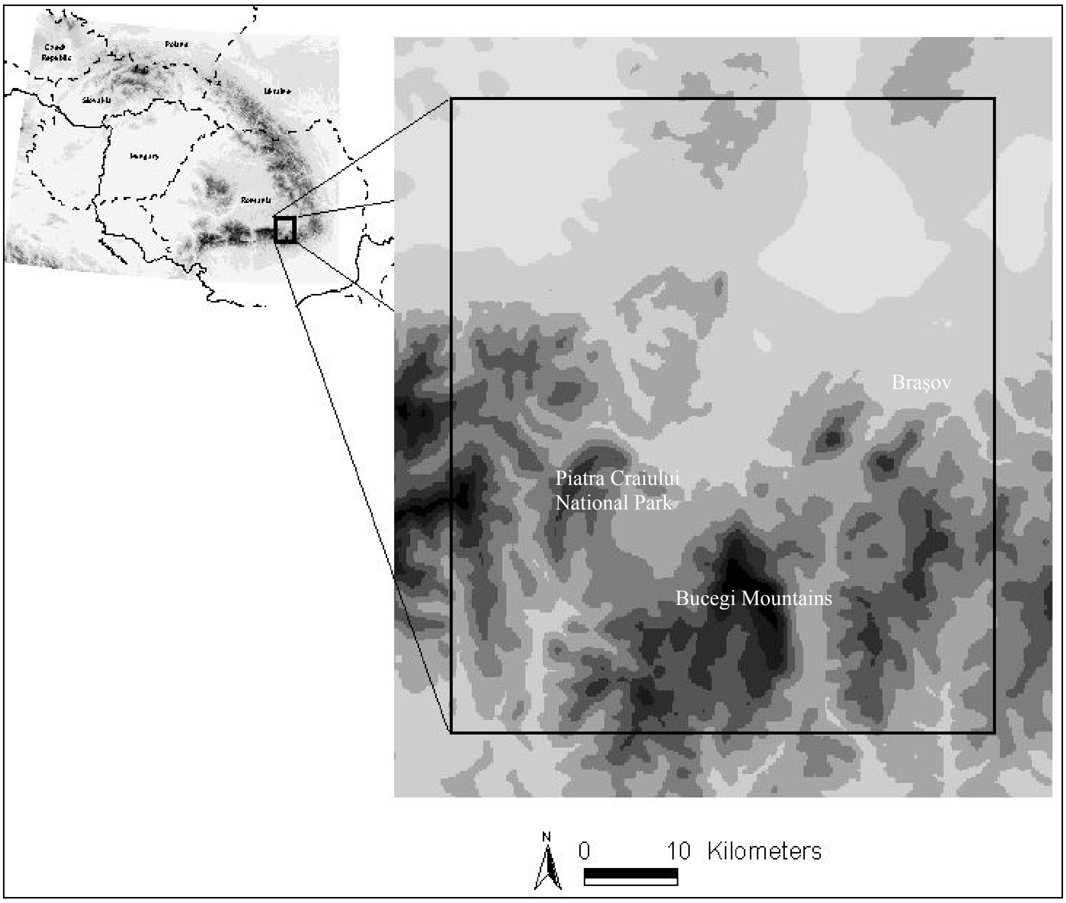


Figure 6.1 – The location of the area where analyses were run with multiple spatial resolution data. Grey shades represent altitude, increasing with darkness.

6.2.1 Source Data used

The selected variables relevant for mapping environmental suitability for large carnivores at 1km and 30m resolutions are the same ones considered at 250m resolution: vegetation cover, altitude and human disturbance (see section 4.2 of chapter four). They were represented by land cover maps, digital elevation models, and presence of cities and roads.

6.2.1.1 Data at 1-km resolution

The land cover data at 1km resolution were obtained from the Alterra Company at the University of Wageningen in The Netherlands. The institute co-ordinated the 3-year Pan-European Land COver Monitoring (PELCOM) project that aimed at producing an updated land cover map of Europe based on multi-temporal analyses of NOAA-AVHRR satellite imagery and ancillary data. The results obtained were assessed for accuracy using 40 Landsat TM classified images, reaching a total average accuracy of 69.2% (Veldkamp *et al.* 1998).

The PELCOM data set covers an area that spans from the Iberian Peninsula into Russia up to 40° Longitude East. The land cover map has 14 classes, and after selecting a subset over the Carpathian region, twelve of them were present. These were aggregated into six classes consistent with those used for the re-classification of CORINE land cover (see section 4.3 in chapter 4). The aggregation is shown in figure 6.2.

PELCOM CLASS	NEW CLASS	ID
Coniferous forest Deciduous Forest Mixed Forest	Forest	1
Grassland	Grassland	2
Shrubland Rainfed Arable Land Irrigated Arable Land Permanent Crops	Agriculture	3
Barren Land	Barren Land	6
Wetlands Inland Waters	Water	4
Urban Areas	Urban Areas	5

Figure 6.2 – The reclassification of PELCOM land cover map

As was previously done with the CORINE land cover data set, the six aggregated classes were then associated with a unique number and separated. The resulting map is shown in fig. 6.3.

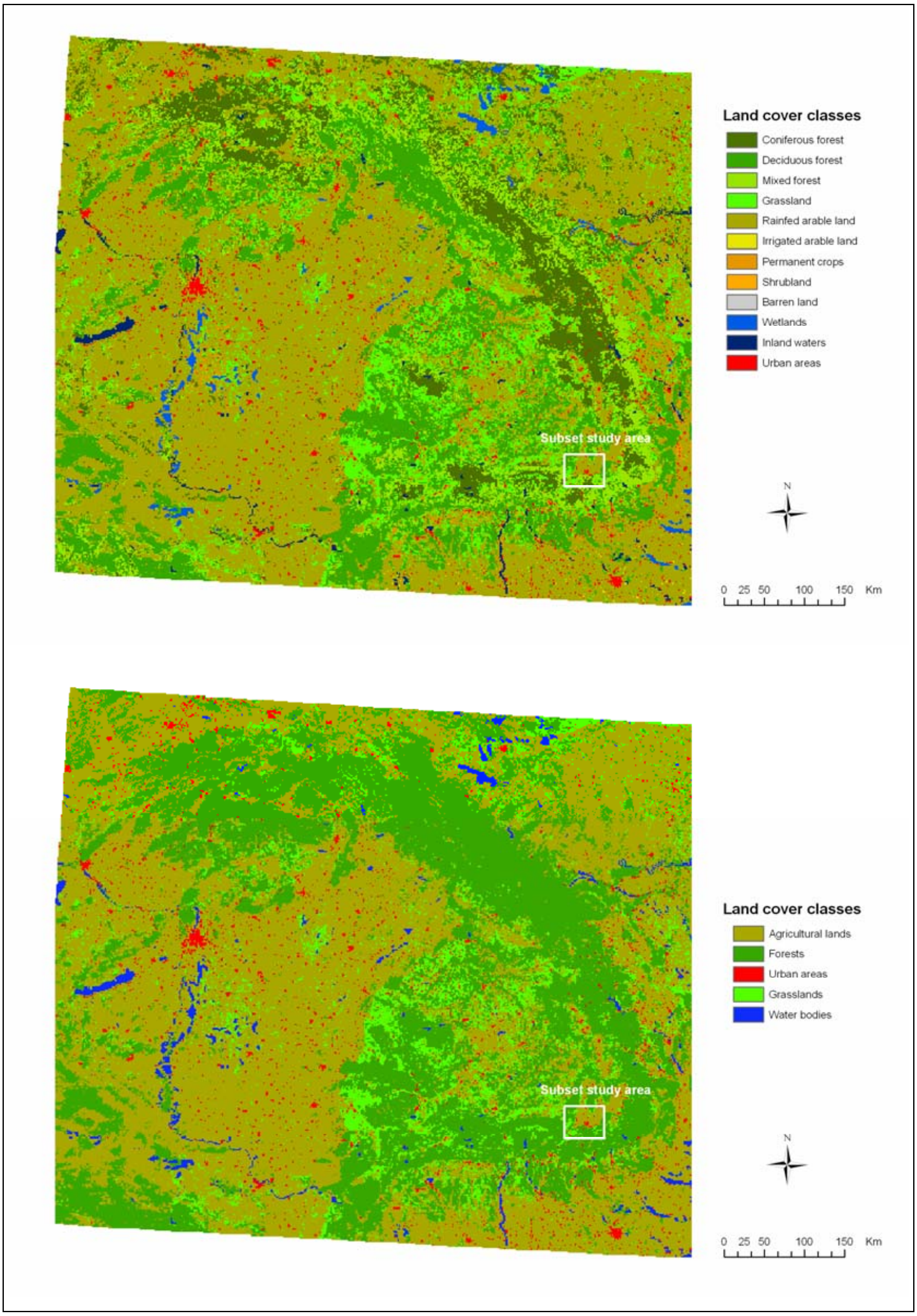


Figure 6.3 – The raster images of PELCOM land cover map at 1km resolution. Upper image: the original data, lower image: the aggregated data. The white box represents the area where analyses at different spatial resolutions were performed.

Subsequently, each class was represented with a separate raster image where the pixels corresponding to the class considered were given a value 1 and the rest were given a value 0. Thus six binary (value 0-1) layers were produced.

There was a seventh land cover (roads) in the CORINE map that was not mapped in the original PELCOM data base. Therefore the road class was generated from a vector map of roads that was available at finer spatial resolution available (see section 4.3 in chapter 4). The roads vectors were converted into a raster image (in Arc-Info) maintaining the reference cell size and extent of the PELCOM data.

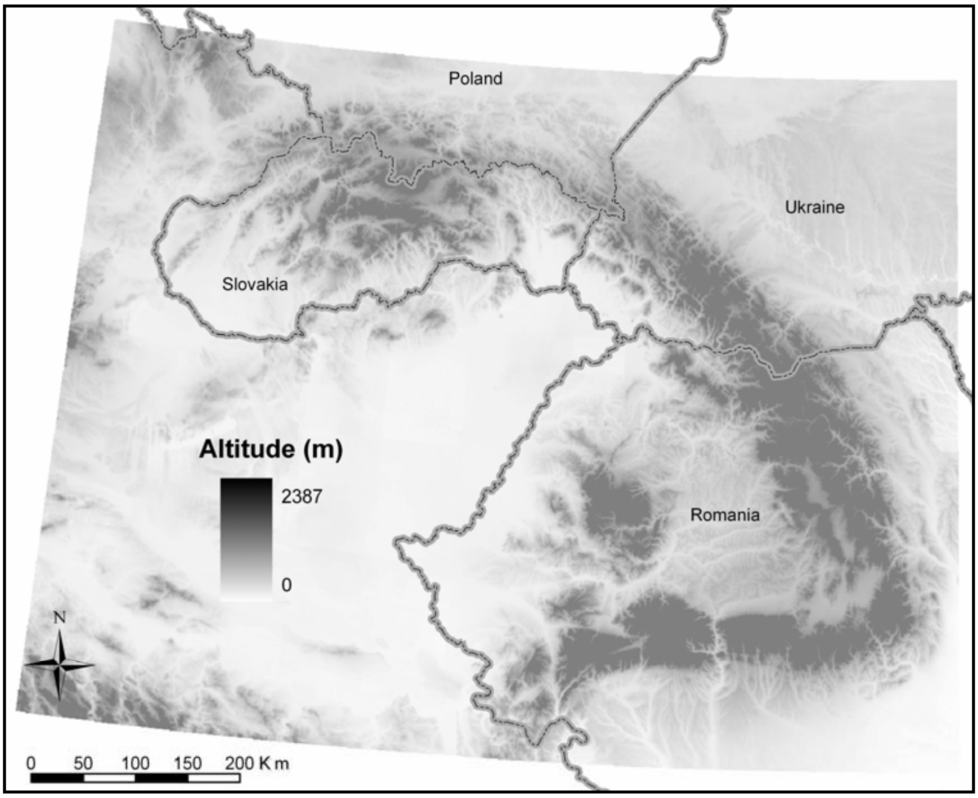


Figure 6.4 – The Digital Elevation Model at 1km resolution produced by the USGS Geological Survey for the Carpathian Mountains. Grey lines represent country boundaries.

The altitude data were downloaded from the United States Geological Survey (USGS) web site, where they are available free of charge. The USGS has produced a DEM at 1 km resolution, called GTOPO30, for the entire world. The source data for the Carpathian region came from the Digital Terrain Elevation Data of the National Imagery and Mapping Agency of USA (USGS 1998) and were downloaded in two parts that needed to be merged. The DEM originally available in the geographical coordinate system (lat/long in decimal degrees) was projected into the UTM WGS84 coordinate system. The raster image is shown in fig. 6.4 as grey shades of increasing darkness according to increasing altitude.

6.2.1.2 Data at 30m resolution

A satellite image produced by the ETM+ (Enhanced Thematic Mapper) sensor on board the Landsat 7 satellite was acquired from the USGS Eros Data Center. The Landsat 7 sensor records reflection from ground features in 7 bands of the electromagnetic spectrum at a spatial resolution of 30m in all but one band (band 6, recording reflectance at wavelengths corresponding to the thermal IR region). The whole image covers an area of 50,342 km^2 approximately, over the south-eastern Carpathians, covering the elbow of the mountain chain in the Transylvanian region. A subset of the image covering the study area in Romanian Carpathians was analysed. The image was acquired on the 5th of April 2001. It was geometrically and radiometrically corrected by the USGS Eros Data Center. This means that the image was corrected for errors due to system noise and sensor motion and was associated to its geographic location with lat/long coordinates. A true colour composite image is displayed in fig. 6.5 using bands 1, 2 and 3 of the original image.

A field campaign was conducted to (*i*) check for geometric correction of the image, and (*ii*) for collecting ground truthing data to use for image classification. The image pre-processing was performed using the software Erdas Imagine (Leica Geosystem 2000).

The geographic coordinates of 45 points were recorded on the ground with a Garmin E-trex GPS, which uses up to 12 satellites reaching an accuracy location estimate of up to 5m. They were used to assess the accuracy of the geometric correction of the Landsat 7 image and the total Root Mean Squared (RMS) error estimated was 27m.

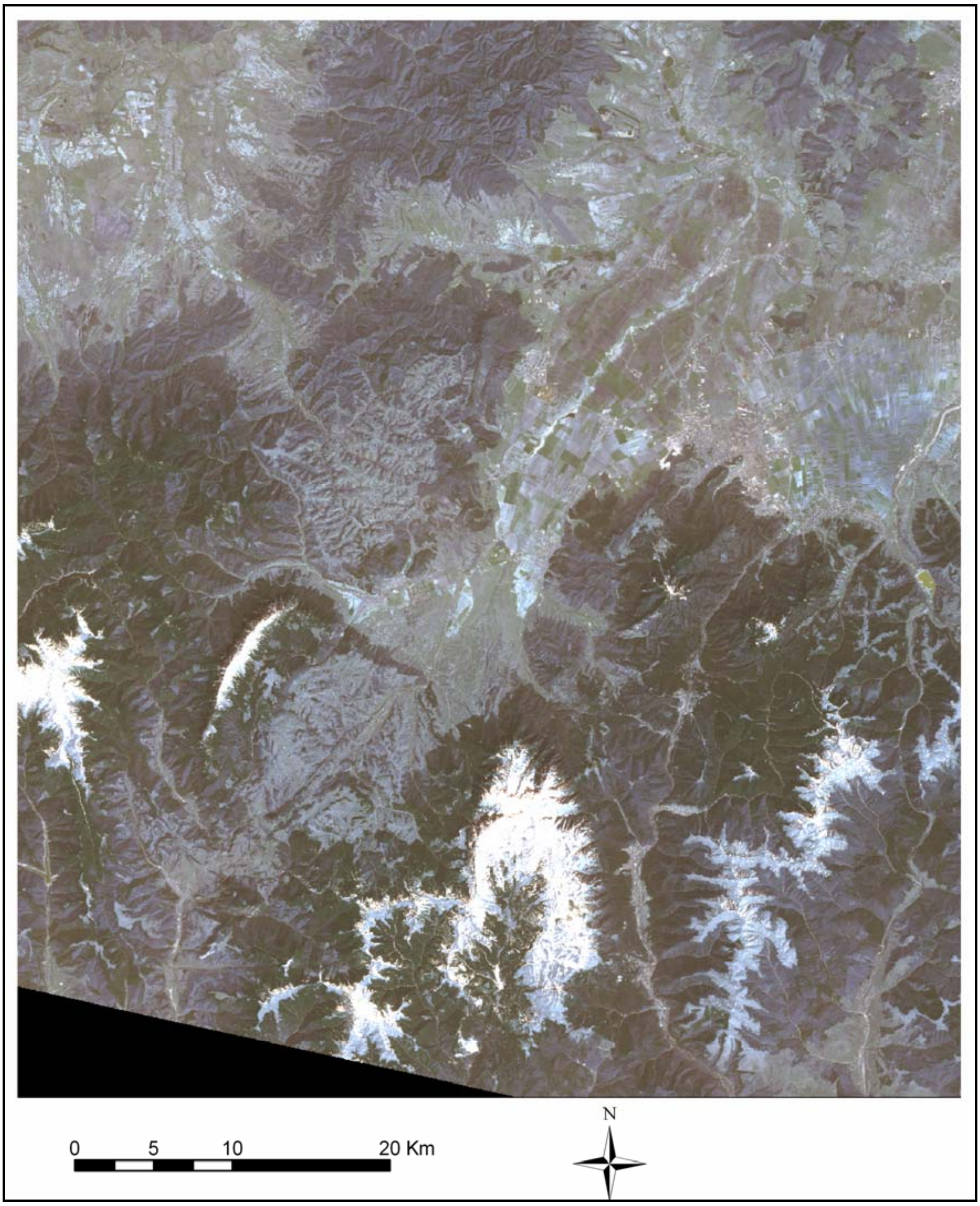


Figure 6.5 – A true colour composite display of the Landsat 7 image (band combination: 1, 2, 3).

The image was classified using a supervised classification of all bands through an Extraction and Classification of Homogeneous Objects (ECHO) approach (Kettig and Landgrebe 1976) in the Multispec software (Purdue University). The ECHO approach uses spectral information of statistically similar pixels for segmenting the image into *fields* before actually classifying it. A contribution to the segmentation process is also given by the spatial autocorrelation between adjacent pixels. Thus the pixels in the image are grouped according to their spectral and spatial characteristics. The result is a comparison of objects instead of single pixels during the actual classification, which requires much less time and computing. Furthermore, the characterisation of each object results from the spectral and spatial characteristics of all the pixels that form them, instead of single pixels inside them. This makes that the classification of each pixel in an object is a result of its spectral properties together with those of its neighbours (Kettig and Landgrebe 1976).

After image partitioning, the method uses a maximum likelihood classifier for classifying objects in the image. Isolated pixels (*cells*) are also classified at this stage. In the present case, a supervised classification was used, providing the system training sites for classification.

The image was printed on a A1 format paper poster (84 x 59 cm, ca.) and taken into the field. After a visual interpretation of the image, eight classes were identified and field observation were made during a period between 15th of April and 30th of May 2002. In the field, land cover characteristics were described covering all eight classes that were visually identified in the image.

The classes were:

1. *Forest* (broad leaved forested vegetation)
2. *Conifer* (evergreen vegetation)
3. *Pastures* (grasslands and hay meadows)
4. *Urban* (urban areas)
5. *Scattered* (particular areas of scattered human settlements)
6. *Agriculture* (cultivated areas)
7. *Transition* (all those areas of limited extent that characterise transition zones between two distinct classes, e.g., bush vegetation at the edge of forests that lead into grassland)
8. *Snow* (areas covered by snow at the time the image was acquired by the sensor)

The exploration of the spectral response of the classes of interest revealed that some of them were spectrally distinct in some bands of the Landsat image, suggesting the classification could be done using some of the bands only. Figure 6.6 reports the average Digital Number (DN) values of 90 pixels within each class over the 7 ETM+ bands.

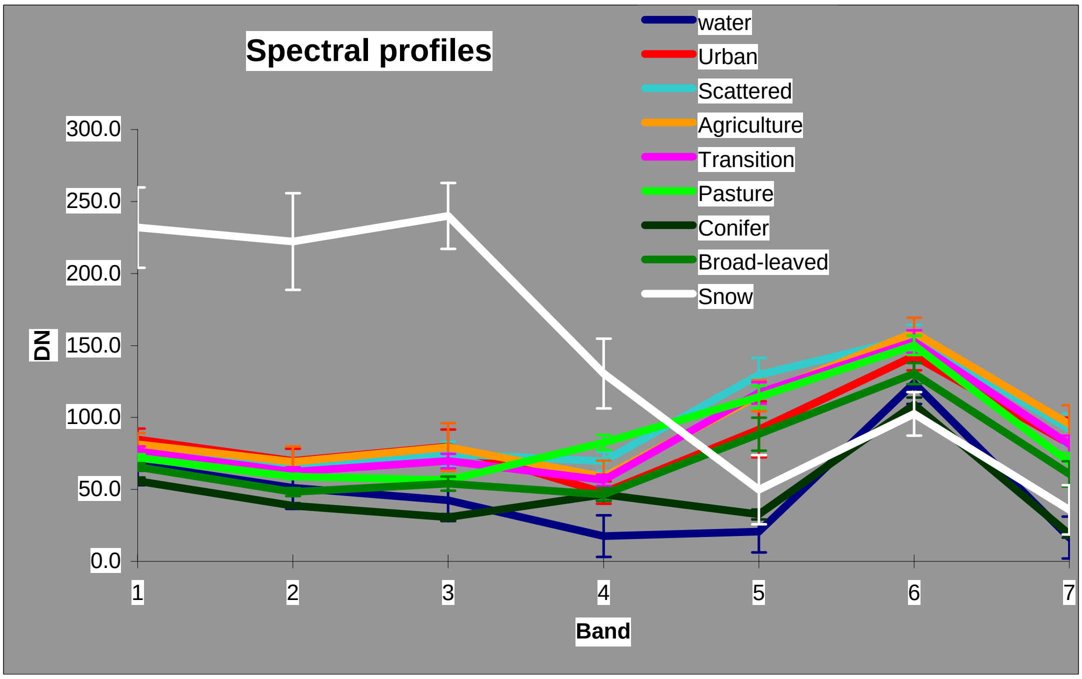


Figure 6.6 – The means and SD of spectral profiles of classes to be identified in the Landsat 7 ETM+ image.

From the average DN values of the classes in each band, it appears that including band 1, 2, 6 and 7 in the classification would add little value to the classification performance. A further explorative analysis was made representing the same samples in the feature space using different band combinations (Fig. 6.7). The exclusion of one or another band was difficult because the identification of all the classes in few bands only was impossible. The situation suggested the need to use all the bands for the classification as some classes only had a distinct spectral behaviour in some band combinations, whereby the others did not appear to be separable. To reinforce such need, a comparison between classification accuracy obtained using bands 2-5 (K = 0.7) only, bands 1-5 (K = 0.6), bands 3-5 and 7 (K = 0.8), and all bands (K = 0.9) suggested that the last option, i.e., using all bands, allowed the best performing classification. The selection of bands to be used for classification was also driven by statistical constraints. In fact, the use of Maximum Likelihood approach in the ECHO Classification requires the training sites to be normally distributed in the used bands. Such an assumption was verified and appeared to be respected for bands 3-5 and 7 only for all classes except snow. Nevertheless, the choice of bands to be used for classification was finally made based on the knowledge of the area, thus using all the bands, as they produced the classification that performed best.

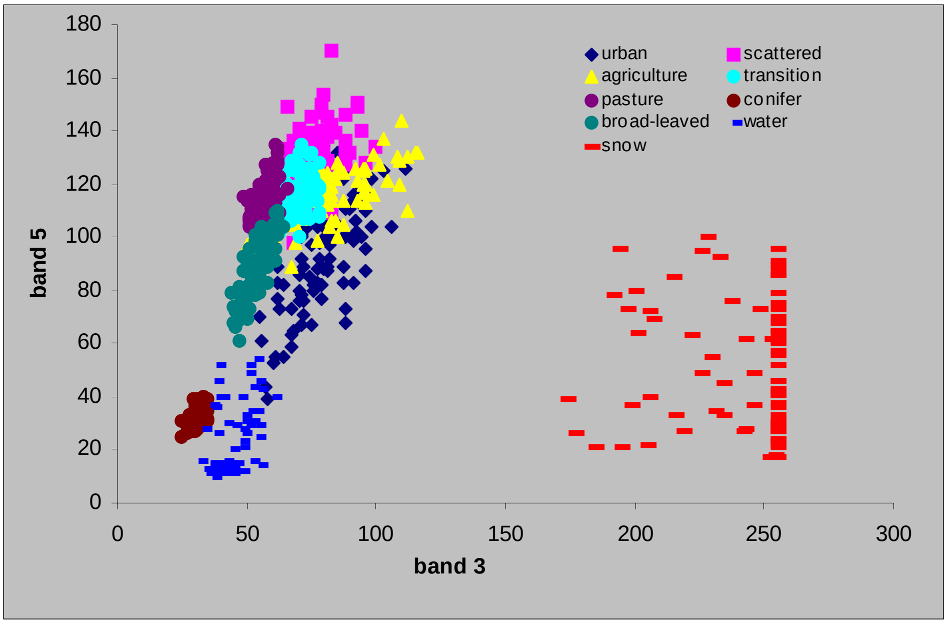


Figure 6.7 A – The representation of class samples in the feature space using bands 3 and 5. Because the class SNOW always had a different behaviour in all band combinations, it will be excluded in the next graphs for ease of representation .

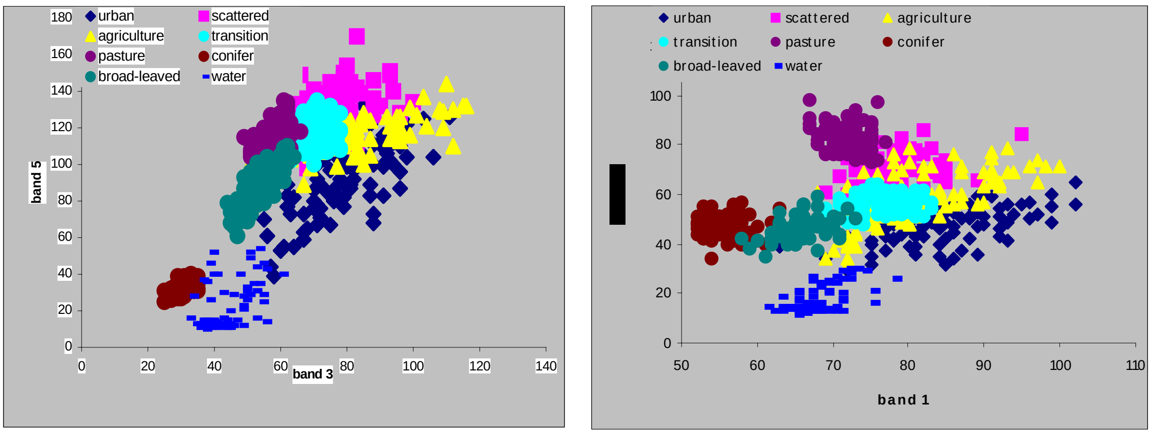
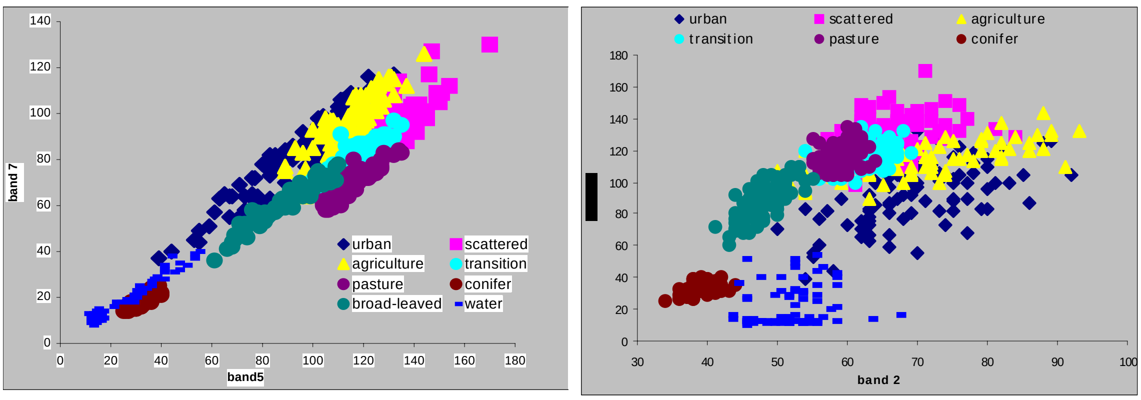


Figure 6.7 B – The representation of class samples in the feature space using the band combinations 3-5 (Upper right), 1-4 (upper left), 5-7 (lower right) and 2-5 (lower left).



An average of 17 (± 5.7 SD) training sites per class were used for training the classifier and their size averaged 154 pixels (± 105 SD). The sites were selected following an opportunistic-random strategy, whereby a stratified random sampling design was adjusted to accessibility and resources (time and fuel) available.

The results of the classification were checked with test fields randomly selected within the areas visually identified in the image. An average of 9 test sites per class was selected and the Kappa coefficient was estimated to be 0.9. The accuracy for each class is presented in table 6.1. The poorest accuracy is associated with the *Pastures* class that appears to have 14.9 % of the training pixels spectrally similar to those of class *Agriculture*. The second worse accuracy is for the *Transition* class – by definition an extremely heterogeneous one. The classification accuracy was tested with the Multispec software, which counts the number of pixels in the test sites that were classified as belonging to another class.

Class	**Performance**
Forest	91.4
Conifer	100
Pastures	47.8
Urban	91.4
Scattered	72.8
Agriculture	96.7
Transition	49.1
Snow	99.5

Table 6.1 – The class performance (expressed in % pixels of the class assigned as expected) in the classification process.

The classification accuracy was also calculated comparing the classification obtained from the ECHO classifier with a manual interpretation of the Landsat 7 image using expert local knowledge in a landscape-guided approach (Zonneveld 1979). The results of the ECHO classifier matched the visual interpretation, accurately specifying for quantity and location for 72.7% of the image, with K = 0.61. The least accurately classified category was the transition class, for which the K-statistics reached a value of only 0.10.

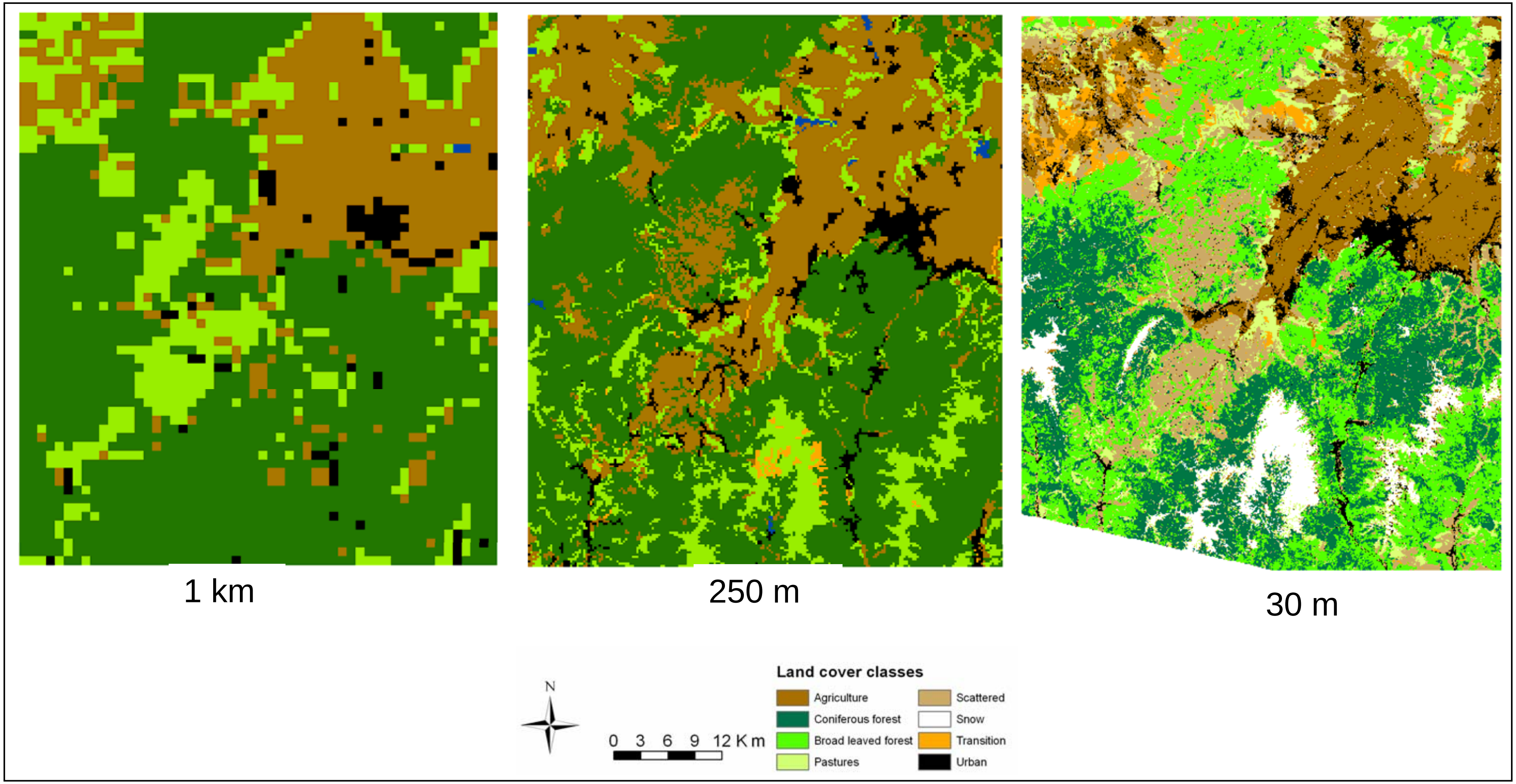
The land cover raster image of the ECHO classification was separated into different binary grids of 1-0 values, where 1 was associated to the pixels containing the variable considered and 0 to all the remaining pixels.

The roads were digitised on screen over the satellite image and transformed into raster binary images.

No altitude data were available at the 30m spatial resolution, but the lack of such information was thought to be compensated by the presence of information of greater detail about the characteristics of the area and the higher number of land cover classes. In fact, the presence of snow may act as a surrogate for altitude.

The three land cover images at the different spatial resolutions, from which the input variables for the Mahalanobis distance were extracted are shown in fig. 6.8.

Figure 6.8 – The three land cover images for the study area at 1km, 250m and 30m spatial resolutions.



6.2.2 Specie's perception of space

The species' perception of space was simulated averaging the environmental variables using map algebra operations with a moving window in the same way as applied to the data at 250m resolution (see section 4.4 in chapter 4). The window sizes used for the raster images at 1km and 30m resolutions are reported in table 6.2, aiming at simulating the perception of space of each species in an area as large as the average home range.

Resolution	**Bear**		**Lynx**		**Wolf**	
	Radius (pixels)	Area (km^2)	Radius (pixels)	Area (km^2)	Radius (pixels)	Area (km^2)
1 Km	4	60.8	6	136.7	5	94.9
30m	133	49.9	183	104	152	65.3

Table 6.2 – The sizes of circular windows used in map algebra operations.

The results of the map algebra operation are smoothed rasters that were used as input in the Mahalanobis distance (see section 5.2 in chapter 5) for estimating the similarity to a reference mean vector representing the variables at the presence locations for the three carnivores. Locations for training the Mahalanobis distance classifier were the same for the analyses across the three spatial resolutions.

6.2.3 Data pre-processing

The model was run separately for each species and the outputs were combined using the minimum function in order to make the comparisons using only one raster for each of the three spatial resolutions considered. The minimum function integrates grids considering the least suitable value between the rasters. See section 5.6 and figure 5.21 for a detailed description of the minimum function and its application within this project.

The raster images at 1km and 250m spatial resolutions were resampled to the finest spatial resolution raster to be included in the comparison, i.e.30m. The resampling was performed in Arc-Info using a nearest neighbour algorithm and setting the cell size and grid origin to match the raster image of the area obtained with the Mahalanobis distance run with environmental variables extracted from the Landsat 7 image. The comparison was then performed using raster images that had consistent cell size of 30x30 m.

6.2.4 Method of comparison

The comparison of results obtained at different resolutions were compared using the VALIDATE function in Idrisi (Clark Labs) (Pontius 2000). The three raster images were also overlain in order to quantify the proportions of cells that were consistently included in the same suitability classes at the three spatial resolutions. The VALIDATE procedure calculates the accuracy of quantity and location between pairs of raster images by calculating the separate K-statistics for both such aspects (Pontius 2000, 2001). The K-statistic is a measure of the difference between (a) the obtained classification agreement between two maps and (b) the agreement that would be obtained if the maps were created only by chance. See section 5.5.2 in chapter five for a detailed description of K quantity and K location.

6.3 Results

The environmental suitability images produced by the Mahalanobis distance showed some consistent patterns across spatial resolutions (see fig. 6.9). The overall percentages of area covered by each class are sketched in figure 6.10. Although a similarity exists between the resolutions of 1km and 250m in quantities classified, the spatial distribution pattern appears to be more similar between the 1km and 30m raster images than between the 250m and 30m suitability images, for example in the lower left corner there is a striking difference between the 250m and the 30m suitability maps (fig. 6.9).

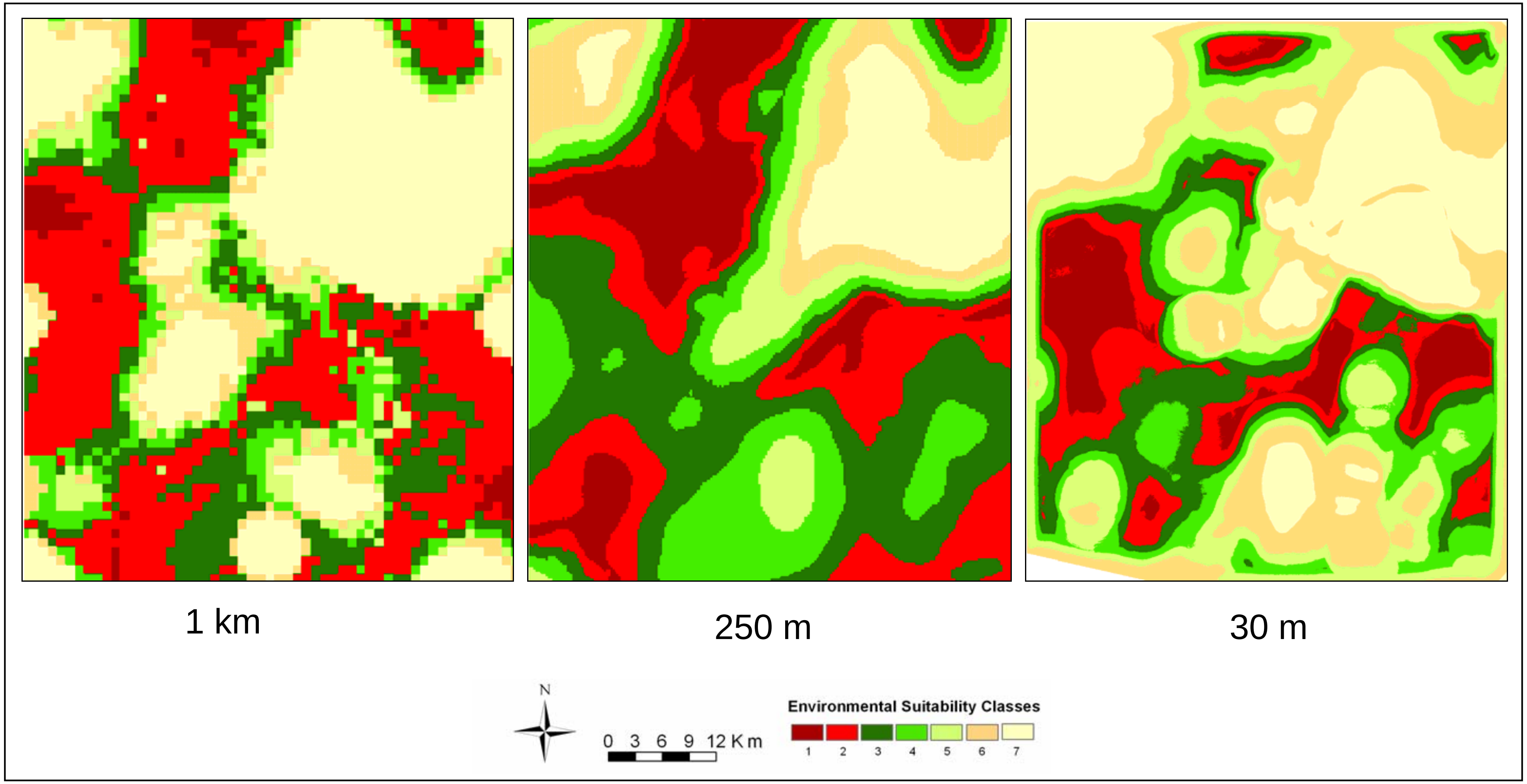


Figure 6.9 – The three outputs of the suitability classification process using input variables at 1km, 250m and 30m spatial resolutions. Different colours represent environmental suitability classes for the three carnivores.

This visual impression is also confirmed by the pair wise comparison performed in the VALIDATE procedure. The outputs of such comparison suggest that there was a very low consistency in quantity, between pairs of maps while it was higher in location. As a matter of fact, the values of $K_{quantity}$ for the comparison pairs 1km vs 250m, 1km vs 30m, and 250m vs 30m, all assume negative values, suggesting the match of quantity was lower than the one reached by comparing two randomly generated images.

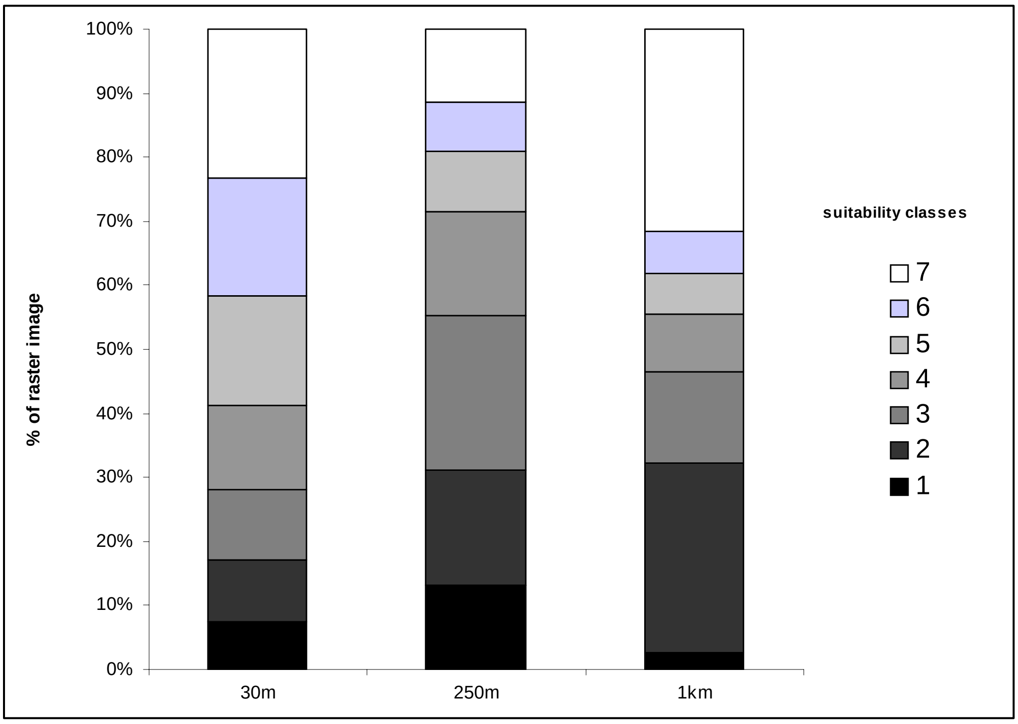


Figure 6.10 – The proportions of the raster images produced by the Mahalanobis distance using input variables at different spatial resolutions included in the seven environmental suitability classes.

Only very small patches in the image are classified as the same class in all raster images of different resolution, their extent ranging from 2.2 (class 1) to 338 km^2 (class 7). The values of $K_{location}$ range from 0.23 and 0.25, the highest value achieved by the 1km vs 30m pair.

The per class analyses produced consistent results across resolution pairs. Comparing results at 1km vs 250m, $K_{location}$ was maximum for class7 (0.9) and minimum for intermediate classes, while location of class 1 indicated a degree of consistency ($K_{location}$ = 0.3). Scaling down and comparing 250m vs 30m, the $K_{location}$ was still maximum for class 7 (0.8) and minimum for class 1 (-0.05).

Going from 1km to 30m the consistency appears to be high for classes 7 ($K_{location}$ = 0.5) and class 2 (0.4), while consistency for class 1 was very low (0.05).

6.4 Discussion

The results obtained by the comparisons of Mahalanobis distance outputs at different resolutions are not unexpected. Increasing spatial resolution of input data inevitably brings about an increasing detail in the environmental variable. Thus the output of the classifier at finer resolutions are expected to differ greatly from that at coarser resolution, even if only because of the details provided.

The variation in results that may be obtained when the same areal data are combined into sets of increasingly lower areal units of analysis is known as the Modifiable Areal Unit Problem (MAUP) from the size point of view. Particularly, the disappearance of some classes form the land cover data used while increasing spatial resolution is one of the recurrent effects of the change of size of the spatial unit considered (Jelinski and Wu 1996). The problem, though, may be interpreted simply as a hierarchical structure of the data themselves, whereby increasing the spatial resolution of observed phenomena increases the detail to be included in the analysis. The increase of the areal unit, then is a *filtering* of the characteristics that are only present in high detail (Tobler 1989). In the present study, the MAUP might affect the results only partially, as the resolution of different input data are adequate for different purposes: 1km for continental approach, 250m for regional approach, and 30m for local approach.

Not surprisingly, the differences between the three outputs in terms of proportions included in each class are great, because they reflect the differences in the detail of the land cover classification. Although the input variables came from different land cover classification procedures, a similar disagreement across spatial resolutions may had been obtained just by degrading the finest resolution data. Aspinall (2001) obtained results that were not consistent when modelling distribution of red squirrels (*Sciurus vulgaris*) at 1, 10 and 20 km resolutions (data at coarser resolutions were obtained through resampling of 1km data). The author suggested that although data at different sampling resolutions all claim to measure the same information about the environmental variable, the spatial resolution at which they are generated sometimes results in very different spatial patterns. This justifies the disagreement obtained in the classification of environmental suitability in the Transylvanian area.

The results of this analysis show that the location of areas classified as potentially suitable for the carnivores has a weakly consistent pattern across resolutions. Due to the large quantity of single pixels that enclose several environmental situations on the ground, few pixels in the image of 1km resolution are modelled as highly suitable, and therefore few places are found that actually are similar to the signature vector. The latter was built within the same resolution frame, thus the “optimum” conditions should reflect the approximation of ground information detected in the 1km pixels. Nevertheless, the coarse resolution may produce outputs that are supported by a few simple conditions. In other words, in the coarse resolution land cover map, the details are lost and a large number of pixels may contain the conditions that satisfy the similarity to the optimum conditions. On the other hand, the same lack of details would offer little opportunity to the optimum condition to repeat themselves within the extent of the study area. This may explain the small areas of class 1 and the large ones classified as suitability class 2.

The reverse situation is found in the outputs generated at 250m resolution, where the information on the environment seem to be detailed enough to be consistent with the classification of the Landsat 7 image. Comparing the input land cover data at 250m and 30m resolutions, there is an inconsistency in the land cover classification that correspond to the area classified as *scattered settlements* in the 30m resolution image. Such area was classified as *pastures* at 1km resolution, and as *agriculture* at 250m. These classes are extremely difficult to separate just having a look at their spectral characteristics within the Landsat 7 image recording bands (see fig. 6.7). Apparently, the scattered settlements and pastures are both included in the regions where the carnivores were detected to be present. Bears, lynx and wolves were never located in areas of mostly agricultural land, although the interspersion of agriculture fields within forested areas may be included in the environmental types preferred by the carnivores. The large patch of suitability class 1 in the top left of the study area in the 250m output image corresponds to areas mainly forested with some agricultural features in the 250m land cover, while it corresponds to an area mainly covered by scattered settlements in the 30m land cover image. The same area was originally classified as “*Land principally occupied by agriculture, with significant areas of natural vegetation*” in the CORINE land cover data set, and subsequently grouped to the *agriculture* class by the author. Keeping this area separated from the broad *agriculture* class in the re-classification process, may had lead to different results in the outputs of the Mahalanobis distance, but the detail provided by the 30m resolution image and the ground truthing allowed the distinction between substantially different classes, thus producing substantially different results.

The overall pattern of spatial distribution of suitability classes appears to be consistent across scales, with the output produced at 1km showing areas of classes 1 and 2 that included most of the areas of classes 1 and 2 of both the images at 250 and 30m resolutions. In terms of conservation actions, this may be an overestimation of areas potentially suitable for the three carnivores. On the other hand, the results obtained at 30m resolution may be conservative in that the areas of class 1 suitability are extremely limited, and the point locations where the three carnivores have been detected may only partially represent the real situation. Each point location represents only the environmental conditions within a square of 30x30m. This is much more conservative than using the environmental conditions present in 250x250m or 1x1 km cells. In order to have a representative set of environmental conditions for the three carnivores within the area at 30m resolution, there probably a much greater location sample would be needed than the one that was actually used.

The most constant feature that resulted from the similarity estimator run on variables at different resolution was the location of areas least suitable for the three carnivores. Such areas are consistently classified over the same part of the study area (Mertens pers.comm.), corresponding to urban sites and intensive agriculture lands. Although there have been cases of wolves reported inside cities and bears feeding at garbage dumps within the study area, the locations used for training the similarity estimator corresponded mostly to forested areas.

The methodology used appeared to perform differently according to the spatial resolution of input data. Particularly, the data used for estimating the standard vector seemed to be important for bringing a representation of the range of environmental conditions of areas used by bears, lynx and wolves. This suggested that the training data should change according to the spatial resolution at which analyses are done, and the spatial resolution of input data should be selected accordingly to the extent of the area considered. In this case the spatial resolution of 1km was appropriate when considering the Carpathians in relation to other systems in Europe, the 250m resolution was appropriate for the consideration of the Carpathian Ecoregion as a whole, but when considering local management activities restricted to small areas such the one considered in this comparison, the 30m resolution is more appropriate.

6.5 Conclusions

Those processes that occur at different scales need to be appropriately addressed, particularly when these processes bring about management issues that need intense mitigation procedures, as is the case of carnivore conservation (Sillero-Zubiri and Laurenson 2001).

The comparison of results obtained from classification with different spatial resolutions revealed that problems of inconsistencies might occur when differing sampling resolutions of input data are used. On the one hand, there is the possibility of ground features being overlooked or misinterpreted at coarse resolutions. On the other hand, the fine resolution data provide punctual information that tells little about the general life history of the carnivores (e.g., a small village within a largely forested landscape). Therefore, training data of appropriate resolution should be used in this perspective.

The results obtained in this analysis suggest that the trade-off between cost and benefits should be sought for with care. The use of coarse resolution data may be appropriate only when large areas need to be covered, thus costs should be minimised. At fine resolution, detailed information is needed to use the data provided by the satellite image at their best.

Although the scale at which analyses were performed was the same, i.e., the species' perception of space was kept constant, the details provided by different spatial resolution of input data may affect the ultimate results of the classification, with the potential of being misleading if data of a given spatial resolution are used within an extent that is not appropriate.

7. COMPARISON ACROSS INPUT DATA

7.1 Introduction

The process of mapping environmental suitability for large carnivores in the Carpathians included a preliminary phase whereby the environmental variables needed to be selected for establishing a relationship between them and the presence of the species. As already noted in the previous chapter, when comparing results obtained using different land cover input data, the way each environmental variable is represented through the land over map may have an effect on the final results. Assuming that the geographic distribution of the selected variables (or their proxies) is estimated through the classification of satellite images, it should be noted that the image classification process includes analytical steps that have a strong subjective character that possibly affect the outputs of the analyses which the classified image is used for.

The selection of classes to identify and the approach used in the identification algorithm, the pre-processing steps and the number and types of training data used in supervised classification all can contain sources of error, that would add up with the other sources of error that arise during the mapping process and that could potentially affect the ultimate results of analyses. The subjective choice of the adopted classifier may represent an inevitable source of error, as the multitude of available methods for image classification is certainly an advantage, and all of them may be equally suitable in different situations, so that there is no *right* classification method (Lilliesand and Kiefer 2000).

The majority of environmental processes are dependent on the vegetation structures present in the areas where they take place, and these in turn, depend on the climatic conditions (Fjeldså *et al.* 1997). In the present study, the environmental variables used as input for the Mahalanobis distance represented the types of vegetation cover in the area (see section 5.2 in chapter 2). Because the information needed from the land cover classification was mainly of vegetation alone, the hypothesis that an index of vegetation photosynthetic activity would satisfactorily replace the land cover map as input to the suitability model was formulated, thus avoiding the errors inherent in the classification process. The index used is a ratio of reflectance recorded in different satellite sensor bands, the Normalised Difference Vegetation Index (NDVI) that will be described below.

In the previous chapters, the effects of training data set (as compared with test data set in the validation phase, chapter 5) and resolution of input variables (chapter 6) were discussed, and results showed that the outputs produced by the Mahalanobis distance classifier are consistent across scales, although they may depend on the training set used.

In this chapter, the hypothesis that the Mahalanobis distance classifier outputs would not be significantly different when produced with a vegetation index from those produced with a land cover map was tested using data at 1km spatial resolution over the whole Carpathian region.

The application of unclassified images for resource management purposes has proven reliable when the processes targeted were directly correlated with environmental variables easily and clearly detected by satellite sensors. The main advantage of the NDVI is that – being a ratio between reflectance in different bands – it corrects for eventual errors due to topography and shade and compensating for variation in illumination due to terrain (Lillesand and Kiefer 2000). This is particularly important in mountainous areas like the Carpathians. For ease of computation, the comparison was only performed for one species, and the bear was selected because its perception of space was the smallest of the three species (see table 6.2 in chapt. 6), hence the smoothing of ground features through the map algebra operation was minimal.

7.2 Data pre-processing

The hypothesis that the Mahalanobis distance classifier would produce consistent results both using the land cover map and a vegetation index was tested by comparing the output maps. The use of NDVI instead of other vegetation indices was selected because of the easy calculation and the adequacy for integration of different images over the study area.

The data were obtained from the images produced by the Advanced Very High Resolution Radiometer (AVHRR) sensor on board the National Oceanic and Atmospheric Administration (NOAA) / National Aeronautics and Space Administration (NASA) satellites. The NOAA AVHRR data are available free of charge in their 10-day composite format from the United States Geological Service (USGS). NVDI images from AVHRR data are calculated as a combination of bands 1 and 2 in the following way:

$$NDVI = band\ 2 - band\ 1 / band\ 2 + band\ 1 \qquad (1)$$

Bands 1 and 2 of the AVHRR sensor record electromagnetic radiation in the visible (0.58 – 0.68 μm) and near-infrared (0.725 – 1.10 μm) regions, respectively. Chlorophyll absorbs red light in the visible region. Thus, the visible region of the electromagnetic spectrum that is detected by band 1 of the AVHRR images allows the record of chlorophyll presence and represents a proxy for green vegetation (Jensen 2000). Reflectance recorded in the near infrared region has proven useful for detecting differences in land cover classes such as vegetation/soil, or land/water. It is frequently used for estimating vegetation biomass. The ratio of these two bands combination has proven to be highly correlated with vegetation parameters as green biomass, absorbed radiation by photosynthetically active vegetation (Jensen 2000, Tucker 1978).

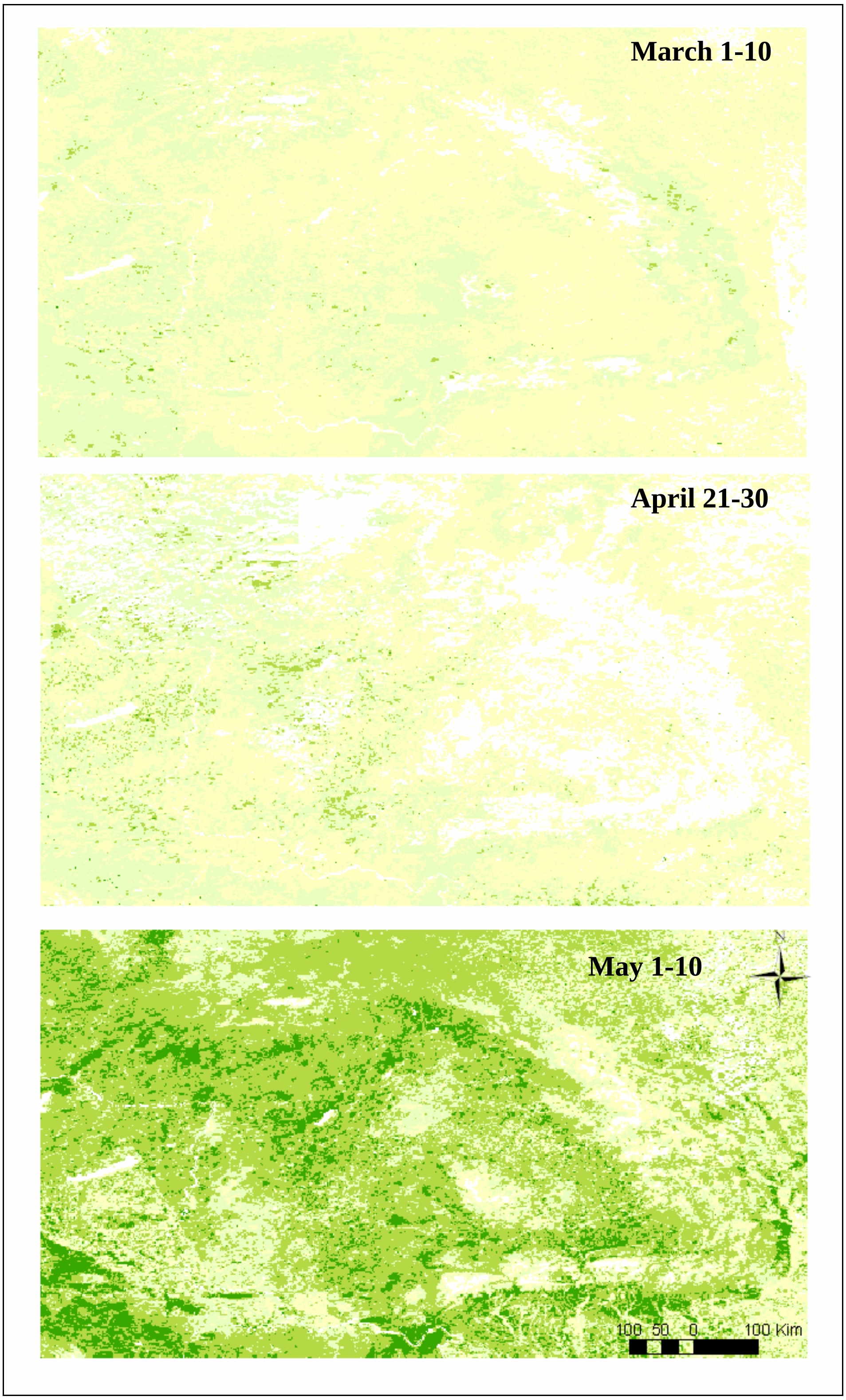
The 10-day composite images result from the combination of images acquired over 10-day periods, i.e., joining adjacent images selected from a sample of ten consecutive days, in order to eliminate cloud cover and disturbed images (Eidenshink and Faundeen 1998). A total of 36 images of NDVI values were downloaded from the USGS Earth Explorer web site together with their corner coordinate in Lat/Long geographic system. They were subset in order to include only the area actually covered by the Carpathian Mountains and then projected into the UTM WGS 84 (zone 35) coordinate system. The availability of so many images over the same area allowed the inclusion of additional information on vegetation dynamics. In fact, a set of images was sought for in order to represent the annual vegetation phenology of the Carpathian Mountains.

After a visual check of the NOAA AVHRR images for presence of cloud, snow, visibility of features and regular distribution over time, 9 of them were selected for analysis. They were selected in order to represent the phenological variation of vegetation within one year. The availability of images was limited to the years 1994-1996 as they appear in the USGS dataset. Only those from 1995 represent a series where most months were captured with no cloud cover at all, and they all came from satellite NOAA-14. Table 7.1 reports the dates when the images were acquired, and they are shown in figure 7.1 as a scale of green intensity whereby at higher green intensity corresponds high NDVI value.

10-day period	1-10	20-30	1-10	21-30	21-30	11-20	11-20	1-10	21-30
Month	Mar	Apr	May	May	Jul	Aug	Sept	Oct	Oct

Table 7.1 – The NOAA AVHRR 10-day composite images selected for analysis.

Figure 7.1 – In the next three pages the NDVI raster images selected are shown. NDVI values increase with increasing green density.



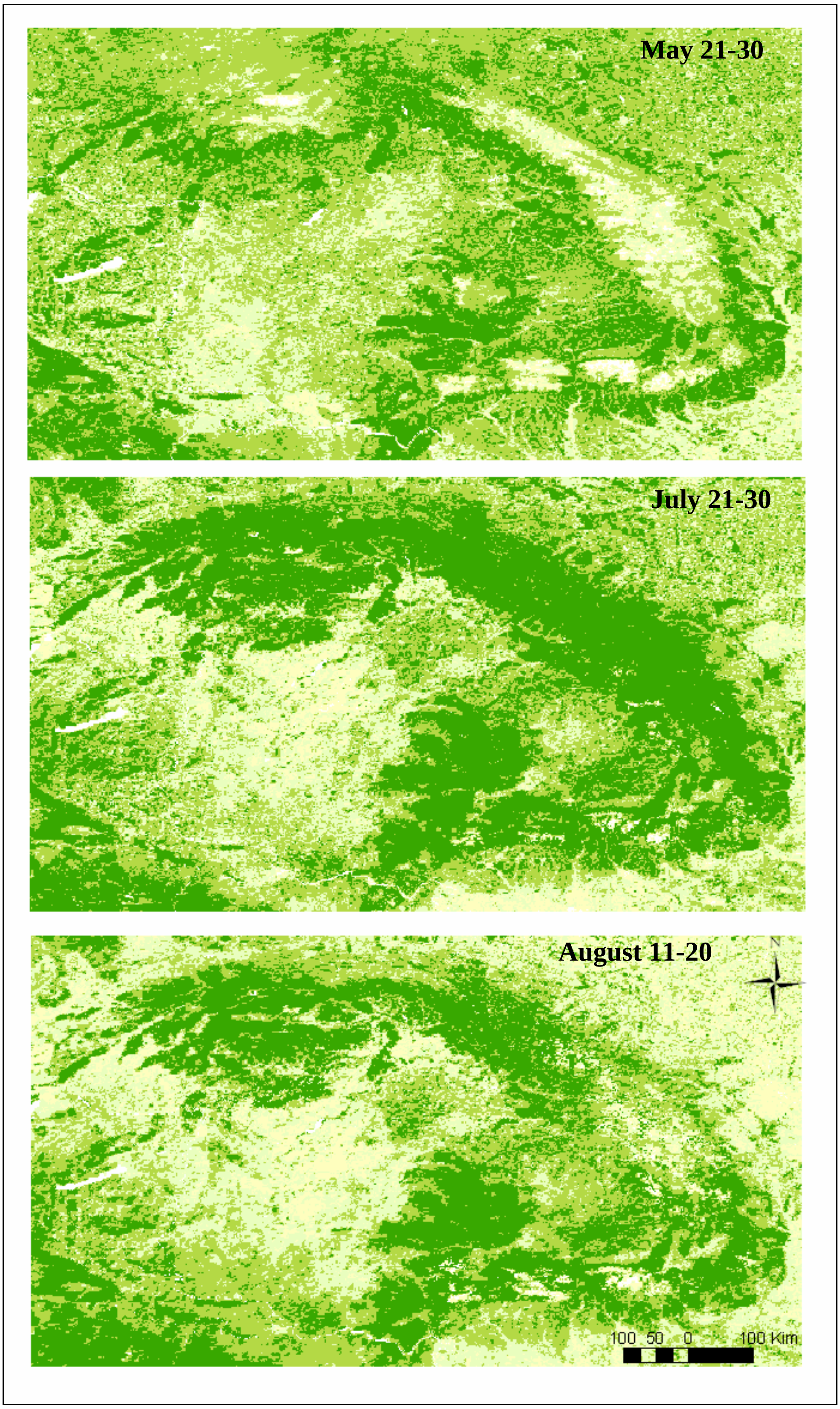


Figure 7.1 – Continued.

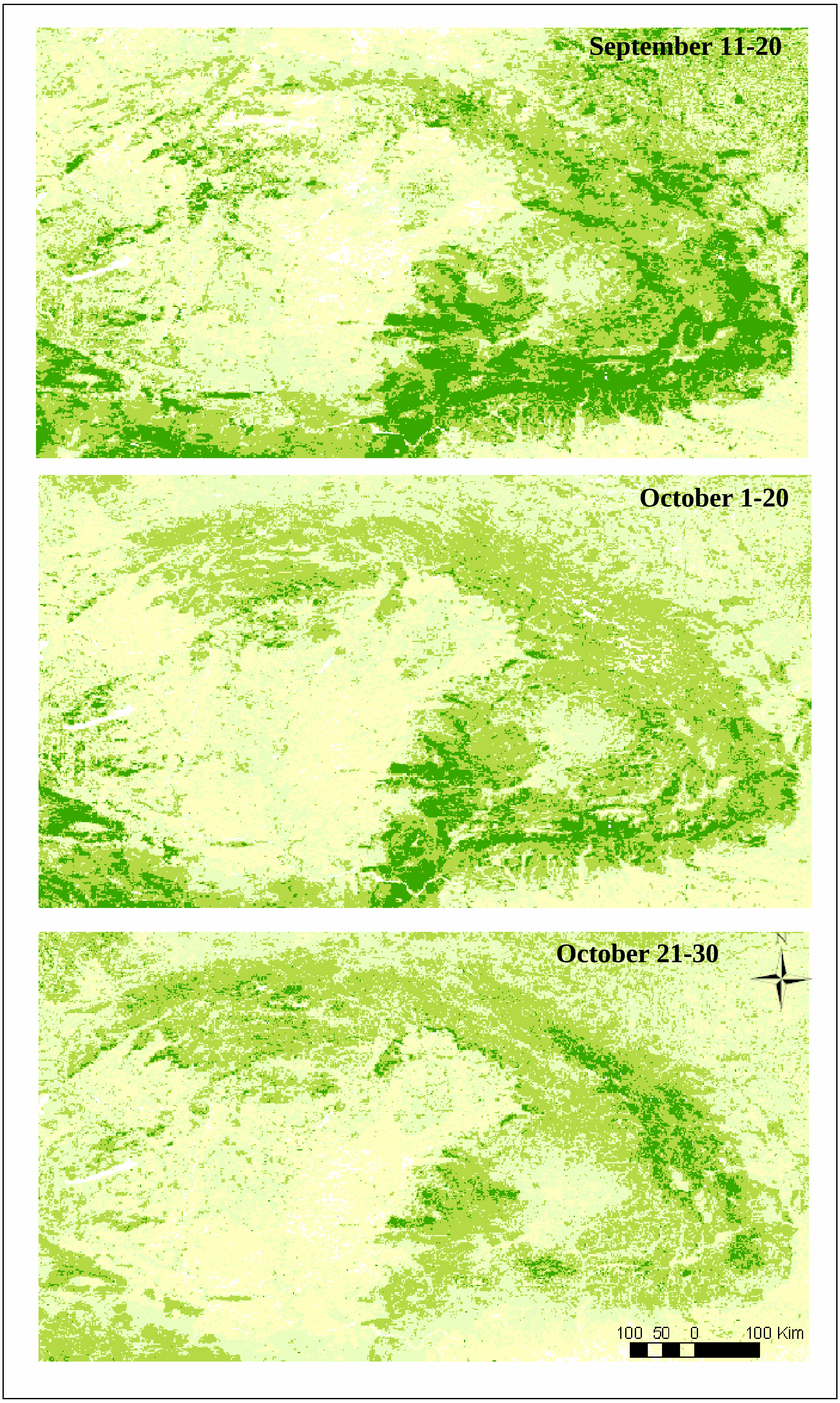


Figure 7.1 – Continued.

The accuracy of the image geometric correction was checked against the PELCOM land cover database produced at the same spatial resolution of 1km by Alterra Company at the Wageningen Agricultural University in The Netherlands (Veldkamp *et al.* 1998, see section 6.2.1.1 for more details on the extent and land cover classes included in the PELCOM data base). Additional digital thematic layers at different spatial resolution (see table 4.1 in chapter four for a list of the digital geographic data available and their spatial resolution or scale) were used for the purpose. A resampling operation using a nearest neighbour approach was necessary to correct for the shift in coordinates that existed between the data sets. A total of 50 GCP were used for achieving an RMS error < 1 pixel.

The map algebra operations for simulating the species' perception of space were applied to the nine NDVI images, using a circular window of the same size that the one used for the PELCOM data base (i.e., 4 pixels radius, see table 6.2 in chapter 6).

Finally, the input variables for the Mahalanobis distance classifier were represented by the nine NDVI images, a raster image of the road system, one representing the urban sites, and a DEM. These latter were the same layers used for modelling using the PELCOM data base.

7.3 Comparison of land cover vs NDVI outputs

The pre-processed NDVI data were used as input for the Mahalanobis distance classifier and the outputs produced were compared with those obtained with the land cover data using the VALIDATE procedure available in Idrisi (Clark Labs). Such module compares two categorical raster images in terms of percentage of agreement between class pairs. It provides the K-statistic (Congalton *et al.* 1983) and gives measures of two components of agreement: quantity and location (Pontius 2002). The K-statistic is a measure of the difference between (a) the obtained classification agreement between two maps and (b) the agreement that would be obtained if the maps were created only by chance. The K-statistic achieves values between 0 and 1, although negative values can be assumed as well – and they suggest that the classification results are worse than any that would be obtained by chance. Values close to zero indicate that the classification performance is close to the one that would be obtained by chance (Campbell 1996, pg. 389). The two estimates of quantity and location of agreement are based on statistical procedures that use the expected agreements in the case of a complete quantity and location match; these are used for producing the statistics of $K_{location}$ and $K_{quantity}$.

Because of the difference in the extent covered by the input data a subset of the images was selected for making the comparison. Such subset region coincided with the boundary of the Carpathian Ecoregion as set by Kondracki (1978) according to the geomorphologic characteristics of the mountain range (see figure 3.5 in chapter 3).

In addition to the VALIDATE procedure that calculates the Kappa statistics on a per class basis, a comparison of the proportions of the extents considered included in different suitability classes in such subset of the Carpathians was performed.

Furthermore, 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 standard deviation (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.

7.4 Results

The spatial distribution of suitable areas for bear in the Carpathians was different when using the series of 9 NDVI images rather than the land cover image, although a general consistency in the spatial distribution of areas associated with different suitability classes is detectable (fig. 7.2).

The major differences arose in three particular areas: the Transylvanian plane in the Carpathian elbow, the Ukrainian Transcarpathia region and the Central Slovak mountains belonging to the Muranska Planina area (fig. 7.2, in black circles).

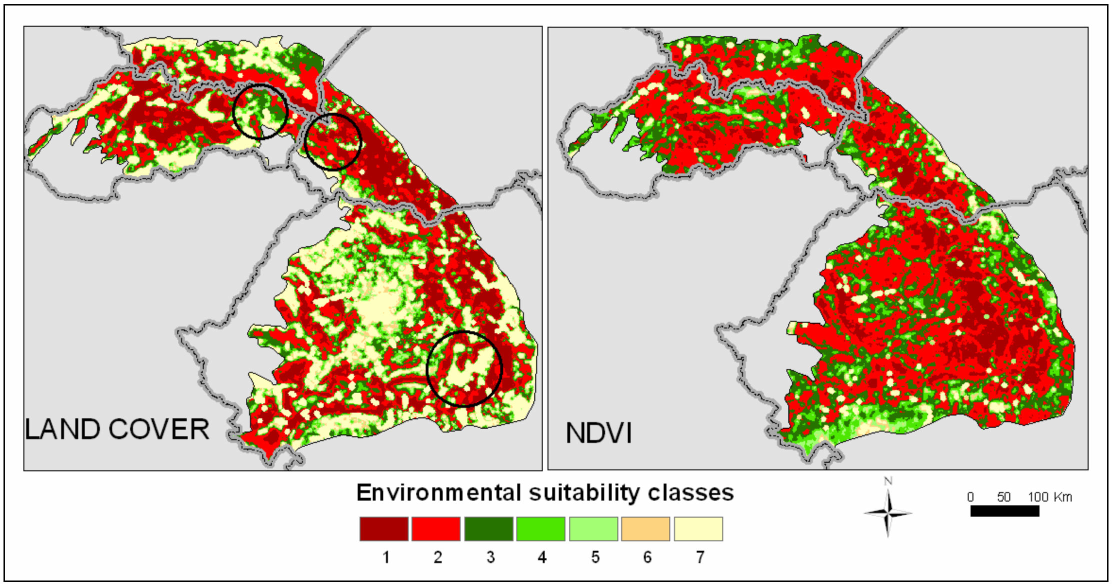


Figure 7.2 – The graphic representation of the Mahalanobis distance outputs produced with the land cover and the NDVI series at 1km spatial resolution for the Carpathian Ecoregion.

The differences in proportions of the seven suitability classes included in the Carpathian Ecoregion is particularly marked for class 2 and 5 to 7. Suitability class two covers up to 43% of the area (fig. 7.3) in the output produced using the NDVI, while classes 5 to 7 only include marginal areas mainly in correspondence to urban areas and valleys where the density of roads is higher. The distinction between agricultural areas and pastures that is provided by the land cover data allowed the exclusion of the former areas from the higher suitability classes. They were included in the suitability class 6 and 7 in the output produced using the land cover data, while they appear to be included in classes 2 to 5 in the output generated using the NDVI. The differences between pairs of proportions for all classes were statistically significant ($12 < z < 17$, $p << 0.01$ always).

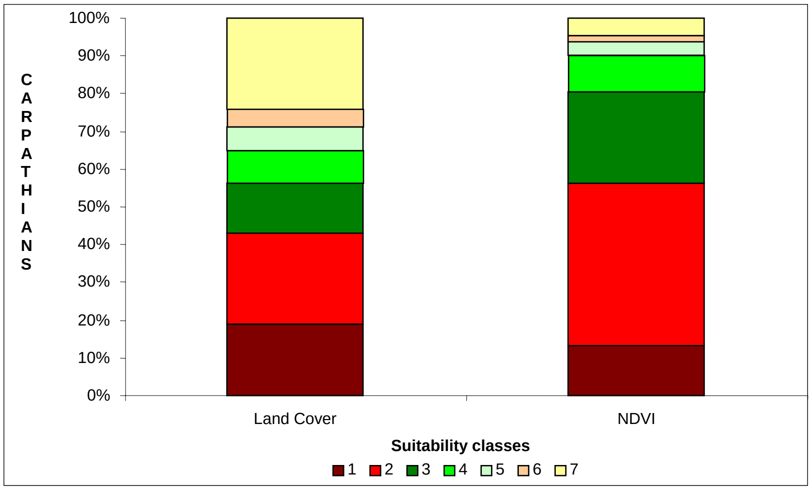


Figure 7.3 – The proportions of the Carpathian Ecoregion included in the suitability classes estimated by the Mahalanobis distance using land cover (left) and NDVI (right) data. Note the large differences in proportion of class 2 in the NDVI output (42.7% vs. 24.1%) and the large portion of class 7 in the land cover output (24.0% vs. 4.6%).

The results of the VALIDATE procedure indicate that 70% of the images are consistently classified and the overall K = 0.51. The location of pixels in the different suitability classes was poorer than the ability to estimate the quantity of Carpathian area included in each class, reaching a $K_{location}$ value of 0.66 and a $K_{quantity}$ of 0.8.

The results obtained using the nine NDVI images show that most suitable areas are associated with least phenologically variable environments. Particularly, the different classes appear to be distinguished by different values of NDVI variability as expressed by the SD for each image, rather than absolute mean NDVI values. Figure 7.4 shows the trends of mean NDVI values per class throughout the time period considered, while figure 7.5 shows the mean SD of each class against time. In the latter figure, the increase of variability with decreasing suitability degree is represented as mean and SD of standard deviation values of NDVI for each class in the images considered for analysis.

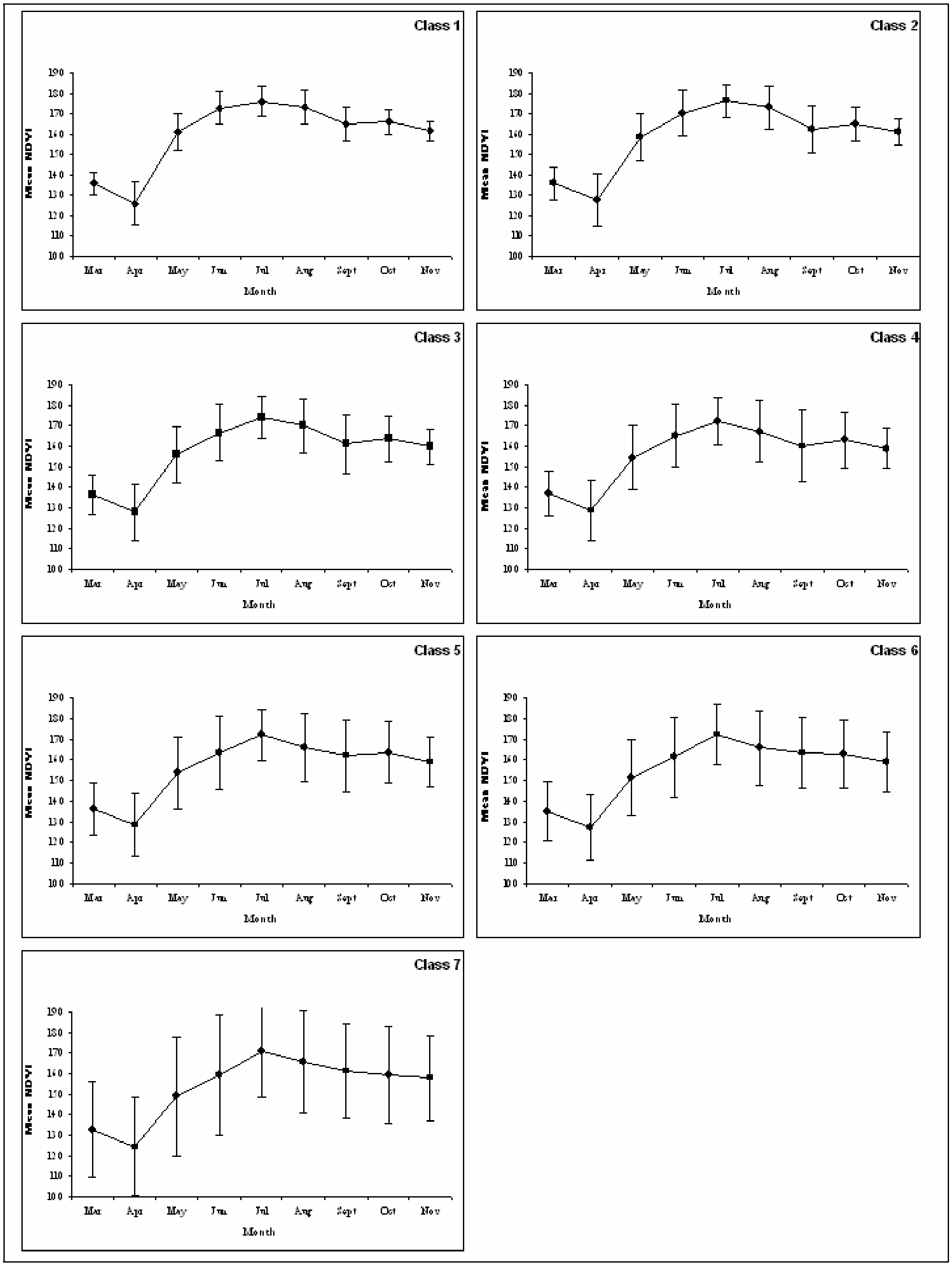


Figure 7.4 – The mean (and SD) values of NDVI of cells included in each suitability class through time.

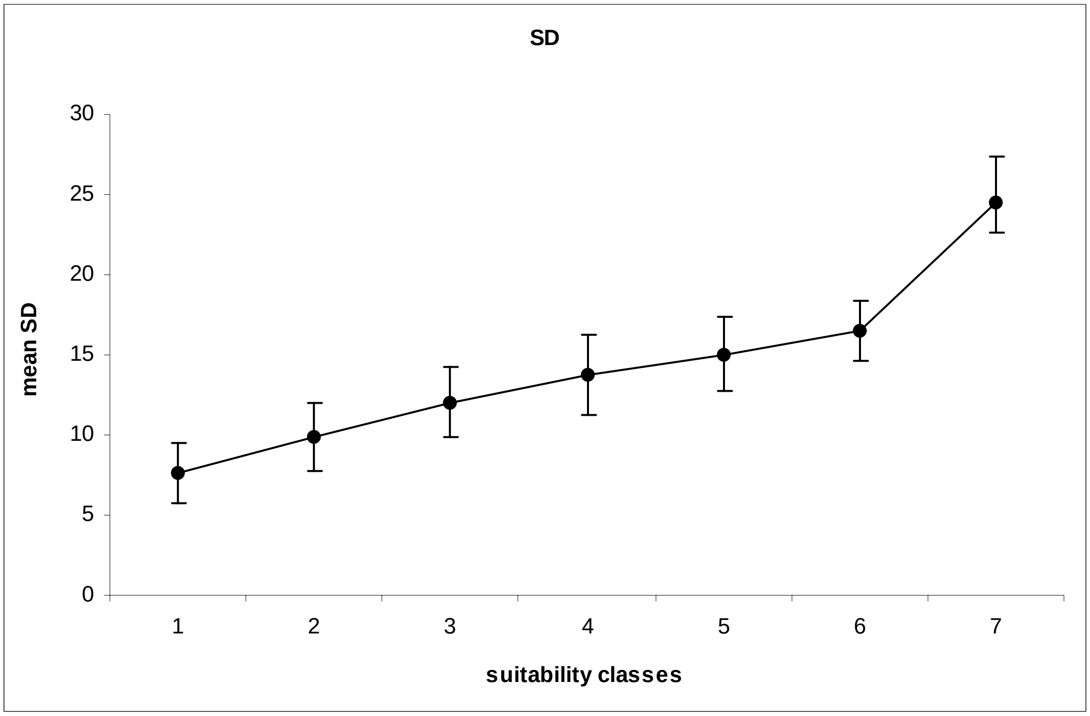


Figure 7.5 – The mean temporal variation of NDVI values for each suitability class.

It is also noticeable that class 1 never included pixels with very low NDVI values, the minimum ranging from 10 to 140 (table. 7.2).

Class	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	10-163	10-177	10-195	110-194	10-191	112-195	10-195	117-191	140-184
2	1-187	1-194	1-193	1-194	1-194	110-195	1-195	1-192	1-189
3	1-170	1-179	1-192	1-194	1-193	1-192	1-195	1-186	1-195
4	1-180	1-175	1-185	1-192	1-191	1-192	1-189	1-188	1-188
5	1-173	1-171	1-192	1-192	1-191	1-192	1-189	1-185	1-194
6	1-173	1-159	1-192	1-192	1-190	1-191	1-189	1-185	1-194
7	1-189	1-168	1-195	1-190	1-191	1-191	1-188	1-185	1-192

Table 7.2 – The range of NDVI values in each suitability class through time.

The comparison with the phenological variability in the area shows that the first suitability class is mainly distributed in area of low CV values and high absolute NDVI values, thus being located mainly in forested areas at low variability. Values of phenological variability in the Carpathian Ecoregion ranged from 0 to 15332. Most of the area, though, was characterised by values of CV within 20, as clearly suggested by the mean CV values within classes 1-6 (fig. 7.6). Only class 7 has a high mean CV (69.0), probably affected by few very high values (SD = 887).

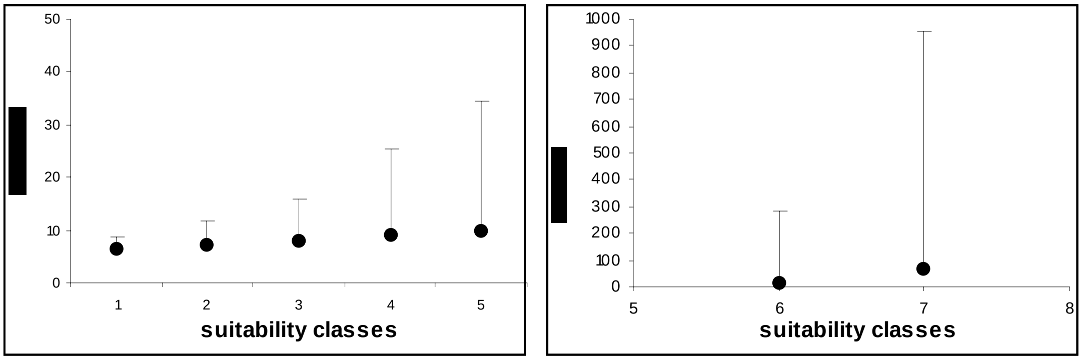


Figure 7.6 – The mean (+SD) values of the coefficient of variation (CV) within the suitability classes. Classes 6 and 7 are shown in a different scale for ease of representation of the values corresponding to classes 1-5.

7.5 Discussion

The results obtained when estimating environmental suitability for bears in the Carpathians using a land cover map and a vegetation index lead to different interpretations. The differences between outputs were irrelevant for intermediate suitability classes, while they were mainly higher for the classes of very high and very low suitability. This may be of significant importance at the management level, when actions on the environment may be taken towards the conservation of this species. At a first stage analysis it might appear that the use of a vegetation index alone may lead to the risk of overestimating the suitable areas for bears, thus not stimulating competent authorities to preserve critical areas, as most of the region seems to be highly suitable.

The Carpathian chain is covered by well managed mixed forests and the vegetation index as produced by combining the reflectance detected by AVHRR sensor bands 1 and 2 may be unable to give enough detail for allowing the differentiation of areas characterised by different kinds of vegetation.

For example, the Transylvanian plain is characterised by intensive agriculture and the NDVI values were not different enough from the pasture areas where bears were sometimes detected.

The Transcarpathia Region of Ukraine is covered with dense forests for most part and the differences between the outputs produced using the NDVI and the land cover may be due to the type of forests that are present, as this may affect the NDVI values. The forests in such part of Ukraine are mainly coniferous with large patches of deciduous forest. These two types of forests were grouped together in the land cover reclassification phase although their phenologies are different. This may lead to diverging results produced by the Mahalanobis distance classifier.

Notwithstanding these limitations, the data showed that when taking the phenological variation into account, results consistent with those obtained with the land cover data may be obtained, particularly in terms of quantity. The high percentage (70%) of the raster image consistently classified as belonging to the same suitability class confirms such result.

Areas highly suitable for bears are characterised by low variability. This may be due to (a) the presence of mature forests, (b) the smoothing effect of map algebra operations for simulating the bear's perception of space, (c) the poor ability of NDVI to distinguish forested areas from pastures. These possible explanations will be discussed below.

(a) Presence of mature forests – the phenology of mature forests in the period considered may not show a high variation in NDVI values. This was explored and apart from the image of April, which appear to be of poorer quality than the others, the values shown in fig. 7.4 would suggest a little NDVI variation through the time lag considered. Furthermore, the majority of forests in the Carpathians are mixed, broad-leaved (*Fagus* sp. and *Quercus* sp.) and evergreen (*Pinus* sp., *Abies* sp). The presence of conifers and the image spatial resolution may not be adequate for detecting the phenology of different species of vegetation.

(b) Smoothing effect of map algebra operations – as already noted in chapter 5, the simulation of the specie's perception of space implies a smoothing of the environmental variables, hence a loss of details. This may have an effect on the NDVI values such that the variation may be lowered. Nevertheless, the differences of mean and SD values of NDVI in the different classes, may lead to the conclusion that this effect can be considered negligible.

(c) the poor ability of NDVI to distinguish vegetation types – this vegetation index has proven useful as indicator of relative abundance and activity of green vegetation (Jensen 2000). One of the main advantage of the index is its ease of calculation. A number of corrections and modifications have been developed in the last decades, and were not applied here for limiting the processing of original data. The limited availability of AVHRR images that virtually excluded the winter season from the time series used because of unacceptable presence of snow and cloud cover, could have affected the ability of NDVI to detect different vegetation covers. The coarse spatial resolution of the images also contribute to this limitation.

The use of NDVI has been extensive in the last decades for many application, e.g. globally mapping vegetation (Justice *et al.* 1985), prediction of fasciolosis transmission in Bolivia (Fuentes *et al.* 2001), forest classification (Dymond *et al.* 2002), among others. In most studies, though, the NDVI was used together with complementary data or transformed information that could improve its performance.

In this work, it was found that although the environmental suitability for bears is not only dependent on vegetation biomass, the use of multitemporal NDVI at 1km resolution may prove satisfactory if used over large areas, such the whole Carpathian Ecoregion, but the results obtained may risk to overestimate the extent of environmental suitability because of the poor ability of NDVI at the spatial resolution used to distinguish between different vegetation types.

7.6 Conclusions

The results obtained in the present study suggest that an accurate estimate of the distribution of areas that are potentially suitable for bears in the Carpathians may not be done from vegetation information alone using data at coarse resolution.

The use of unclassified satellite images for estimating the environmental suitability for bears in the Carpathians seems to be constrained by the ability to distinguish different types of vegetation cover. The use of a vegetation index instead of a land cover map is supported by the assumption that the only determinant class for bears is densely forested areas, thus homogeneously active vegetation. Even if this may be true in an ideal situation, the human occupation of forested areas that are interspersed with agricultural land may increase the extent of areas unsuitable for bears.

The image classification process does represent a stage when potential errors may be added to the modelling flow, but the amount of information gained with the classification may compensate such a limitation. Image classification is labour-intensive and expensive when ground truthing is implemented. The trade off between the advantages obtained with the use of classified images and the use of the less costly NDVI images (i.e., the balance between detail in the input variables and the ease of acquisition), should be sought taking in account the extent of the target area and the information obtained with the less detailed input (i.e., vegetation index only).

8. IMPLICATIONS FOR THE MANAGEMENT OF LARGE CARNIVORES

8.1 Introduction

The main aim of the mapping exercise that has been carried out throughout this project was to contribute to the conservation of the large carnivore populations in the Carpathian Mountains, considering them as proxies for the biodiversity in the area. As already mentioned in chapter 3 (see section 3.4), the Carpathian populations of large carnivores represent the largest portions of the European population of large carnivores, and their management for conservation is crucial. This is particularly significant in the times of economic and political transition that the Carpathian countries are currently undergoing.

The identification of areas that are potentially suitable for the presence of large carnivores may prevent the loss of critical sites in case of intense fragmentation of natural habitats during the process of development of social and economic infrastructures. The possibility that the natural forested areas may be impacted by human activities and would subsequently suffer a considerable fragmentation is suggested by the need of the Carpathian countries to increase their economic stability, and thus using their natural resources, intensifying the timber industry, for example.

The four countries of the project area have a common recent past of communist rule, during which all the land was owned by the State and exploitation of natural resources was highly regulated and controlled by central statutory bodies. In the process of democratisation, the land was (in some cases still is or is not yet) given back to the owner prior to the communist rule. The process of privatisation may have a strong impact on the maintenance of natural landscapes and rural activities, thus modifying the situation where large carnivores currently live.

In this chapter, an overview of the current management strategies of large carnivores in the Carpathians will be given, together with an analysis of the areas currently under protection from human activity that include areas highly suitable for carnivores. Finally, the contribution of the modelling outputs to the conservation of bears, lynx and wolves in the Carpathians as a tool for the identification of areas where conflicts with human activities might occur will be discussed. This will be done using data on damage suffered throughout the Carpathians and the location of shepherd camps within a subset region where data at finer spatial resolution are available.

8.2 The management of large carnivores in the Carpathians[1]

The Carpathian population of large carnivores is the largest in Europe, representing nearly 1/3 of all the European carnivores. The current management of carnivores in the Carpathian countries is mainly based on the regulation of hunting activities. Although the Carpathian Mountains extend across different countries, these have relatively similar historical backgrounds with respect to hunting legislation.

8.2.1 The Hunting Legislation in the Carpathians

The hunting tradition in Poland, Slovakia, Ukraine and Romania is deeply rooted in the culture of local people and hunting activities are regulated by structured legislation. The majority of the forested territory (up to 80%) of Poland, Slovakia, Ukraine and Romania belong to their respective States, and so do the wildlife that live in it. The territory of each country is divided into hunting management units, called Hunting Grounds (HG). These cover different areas in different countries (area ranging from 2,500 to 10,000 ha), but the approaches to their management are consistent across the ecoregion (table 8.1).

The management of HG is regulated by plans usually produced by the non-governmental management bodies. In some cases, a consultation with the forestry inspectorate takes place, e.g. in Poland. Hunting permits are issued by the managers of the HG (see table 8.1). Different permits are issued for hunting game and trophy animals. Game hunting permits must be purchased in all countries except Poland. In the latter, members of hunting clubs can hunt free of charge up to the quota they have been allocated by the HG managers, and they are obliged to deliver the harvested game to the managers who reimburse them for hunting expenses (petrol and equipment maintenance), unless they want to buy the meat at market prices. Permits to hunt in HG administered by State Forestry must be bought in all countries, while special permits are issued for the hunting of trophy animals.

[1] Part of this section was published as: Salvatori *et al.* (2002).

Country	Statutory Body	Law No.	HG Management
Slovakia	Ministry of Agriculture	99/1993, 172/1975	14 % Ministry of Agriculture 86 % Non government owners (church, municipalities, hunting clubs, etc.)
Poland	Ministry of Environment	147 (13/10/95)	7 % State Forest Administration 92 % Hunting clubs 1 % Research Institutes
Ukraine	Ministry of Ecological Safety	1478-III (22/02/2000)	13.9 % State Forest Administration 80.5 % Hunting clubs 3.9 % Research Institutes 1.7 % Ministry of Defence
Romania	Ministry of Agriculture, Food Industry and Forestry	103 (23/09/96)	26 % State Forest Administration 72 % Hunting clubs 2 % Research Institutes

Table 8.1 – Hunting legislation in the Carpathians. The Statutory bodies and the laws that regulate hunting activities are reported, together with proportions of hunting ground (HG) managed by different bodies. From Salvatori et al. 2002.

Hunting quotas for each game species are established yearly on the basis of density estimates produced by HG managers. Regulations on the methodology to be followed for producing such estimates state that track recording on snow and direct sightings should be collected during winter and spring every year. As a matter of fact, such methods are used very seldom in a systematic way, as deep snow and few available people make the task impossible. No systematic surveys are carried out in Ukraine, where sightings of individuals or tracks are reported in a haphazard manner throughout the year. Only in Romania and Slovakia do the recommended quotas need to be approved by central or local offices of the statutory body.

8.2.2 The population size of carnivores and their current management in the Carpathians

Table 3.1 in chapter 3 reports the estimated population sizes for Poland and Ukraine (in 1999), Slovakia and Romania (in 2000). Such estimates are produced annually by the managers of hunting grounds (HG). The official estimates are considered to be inaccurate by most of the local researchers that were consulted. They consider the track counting conducted at HG level to not account for animals that range across more than one HG. Thus, there is an error of double-counting and an overestimation of the real numbers.

Although the mountainous portion of the Carpathian chain extend over large areas, the extent of occurrence (EO) of each species covers only part of the mountain range. A sketch map of the EO for each species was produced by local researchers (see fig. 5.11 in chapter 5), and was here used for estimating densities of large carnivores in the four countries using the population estimates suggested by the local experts (Figure 8.1).

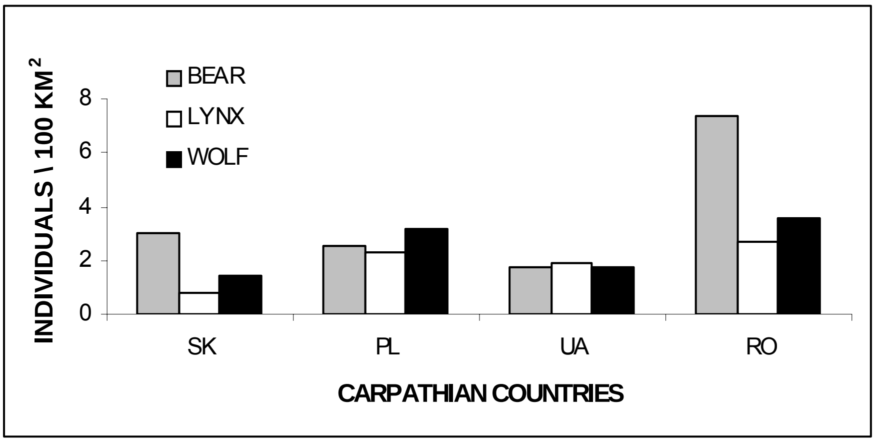


Figure 8.1 – The densities of large carnivores within occupied areas in the Carpathian countries as calculated from population estimates provided by local experts. SK = Slovakia, PL = Poland, UA = Ukraine, RO = Romania. From Salvatori et al. 2002.

The particularly high bear density in Romania is due to historical events, especially the restriction imposed by the communist dictator Nicolae Ceauşescu, who accorded bears total protection in order to have exclusive access to trophies in the late 1970s (Crişan 1994). During the dictatorship, bears started to be fed artificially and the population reached very high levels. Romanian bears currently feed on garbage where locally available (*pers. obs.*). The population can sustain surplus hunting, and sport hunting from foreign hunters may represent a significant source of income for game managers. The income from trophy hunting goes directly to the HG managers (who, in some cases, represent the main population of small villages). In Slovakia and Poland the main source of income in the hunting industry is represented by ungulate trophies (e.g., red deer, roe deer and wild boar) rather than large carnivores.

Bear hunting in Slovakia is restricted to young individuals, and can only be done after special permits are issued by the Slovak Environment Agency. In Poland and Ukraine the species is strictly protected and hunting is only possible on rare occasions when ‘problem’ animals need to be removed. In 1999, 102 bears were reported to be killed by hunters in Romania. In Slovakia 31 bears were killed in 2000, whereas no reported numbers are available for Poland and Ukraine. Damage caused by bears to beehives can be significant in Slovakia, where rural economy is vital for the small communities.

The elusive behaviour of the lynx makes it a very difficult species to hunt. In Romania and Ukraine it attracts little interest from the hunters, as its trophy is not as highly rated as the bear's, whereas in Poland its trophy is considered to be very valuable and it is suspected to be heavily poached (Okarma, *pers. comm*.). In Slovakia it is strictly protected and legal hunting does not occur, although poaching may be considerable (Finďo, *pers. comm*.). The lynx rarely causes damage to livestock. For these reasons, lynx in the Carpathians are not systematically persecuted, although may be illegally hunted, and are consistently protected across the four countries. Romania allows hunting of lynx only in autumn and winter (15 Sept. – 31 March). The main threats to lynx populations may be human-induced habitat modification, poaching and decline of natural prey (roe deer and chamois) due to over-harvest. Lynx hunting in Romania in 1999 amounted to 72 individuals, none were reported in Poland and Ukraine, but 4 special permits were issued in Slovakia. Damage to livestock caused by lynx is generally very low, but its impact in the populations of roe deer can sometimes cause conflicts with hunters, who apply for permits to control the predator.

Wolves are legally considered to be game species across the Carpathians, with the exception of Poland. They can be hunted in Slovakia during the period 1 November – 15 January. In Ukraine, wolves can be hunted with no restriction and sometimes bounties are offered by hunting clubs, whereas in Romania wolf hunting is allowed only for removal of 'problem animals' in areas where conflicts with human activities are particularly acute. A total of 202 wolves were legally killed in Romania in 1999 and 118 in Slovakia in 2000, no numbers were reported for the other countries. Damages to livestock caused by wolf are considered to be significant. No figures are available as no compensation is offered in most countries, but local communities usually claim the impact on flocks of cooperative farms can be very destructive where no economic means are available for maintaining trained guarding dogs (e.g., Ukraine).

8.2.3 Impact of hunting law on management of large carnivores

Despite the existence of some differences in management policies across the four countries considered here, the approach is consistent overall. The adherence of the Carpathian countries to the Bern Convention represents a substantial basis upon which legislation regulating the management of large carnivores can be developed with a pan-European approach. Large carnivores in the Carpathians have the opportunity to exist at high densities, in an environment with relatively few human impacts and in co-existence with human activities. These conditions are extremely valuable and rarely met in other European countries.

Although the conservation status has changed various times through the years, ranging from full protection to designation as game species, this has allowed the recovery of large carnivores in such countries, particularly in the mountain range, where human population densities are lower than the rest of the country. It has already been noted that the protection of bears in Romania was very effective during Ceauşescu's dictatorship. The policy was not particularly aimed at a thoughtful management of wild species, but rather at producing the biggest possible trophies for international hunting exhibitions (Crişan 1994). The restriction of hunting activities and protection of forests and main prey species of the large carnivores permitted the growth of healthy and abundant large carnivore populations in the Romanian Carpathians. In Western Slovakia and some parts of southern Poland, where large carnivores were locally extinct in the past, their return was problematic, as local communities had lost the habit of protecting livestock and beehives. Damage to livestock and agriculture is still suffered and claims are seldom put forward. As an example, in Slovakia it has been reported that large carnivores killed a total of 168 sheep/goats in 2000. This is only a partial figure as no information about non-compensated damage is available. In Ukraine no economic resources are available to maintain trained guarding dogs.

The division of the countries' territory into HGs shows how important hunting activities have been in the past and still are at present. The de-centralisation of management has the advantage of giving responsibility to local people, who directly take advantage of the quality of the environment and its game. Fine-scale control over national property was a priority during communist rule and the heritage left to the current generations is a well-structured system of regulation. Unfortunately, in the majority of cases, this structure is well designed only in theory, as in practice the control over illegal hunting is extremely inefficient (Hunchack 1999). Nevertheless, the revenue generated by hunters and HG managers has stimulated them to make an effort to maintain healthy game populations to ensure fruitful future hunting seasons. This is particularly true for post-communist times, when the revenue from hunting is effectively allocated to local HG managers and the hunts are open to foreign hunters at high prices (bear trophy hunting can cost up to EUR 12,000 in Romania).

The management of game species has an active character in the Carpathians, as shown by the setting of annual hunting quotas based on population estimates produced by local personnel of the HG management bodies. In spite of the theoretical robustness of such management action, the whole process is greatly weakened by the considerable unreliability and inaccuracy of such estimates. Where guidelines exist for the estimation of game abundance, they are seldom followed. Errors in the estimates for large carnivores are amplified by the use of large areas by such species, leading to a risk of double-counting when home ranges cross HG boundaries (Voskar 1993). In terms of hunting quotas, such inaccuracy is often reflected in overestimates of large carnivores populations that subsequently risk being over-harvested.

The strict legislation regulating hunting activities, such as payment of permits and hunting quotas, do offer valuable opportunities for the long-term conservation of large carnivores in the Carpathians. Notwithstanding this potential, the regulation of hunting activities is highly monopolised by hunting clubs (the majority of the Carpathian territory is managed by hunting clubs, see Tab. 8.1) and the law enforcement process is often unsuccessful, as officers do not consider illegal hunting as a social offence.

In addition to the strong hunting influence in the management of large carnivores, the management of the land towards the conservation of biodiversity and the protection of areas from human exploitation is also strongly dominated by the needs of the Carpathian countries to join the European Union. The strongly rural-based economy of the countries inevitably comes into conflict with the presence of large carnivores. The geographical distribution of areas characterised by potential conflicts between carnivores and humans represents a further contribution to an integrated approach to carnivore conservation in Europe. This will be the subject of the following section.

8.3 Spatial distribution of large carnivores-human conflicts[2].

The identification of areas where the presence of large carnivores conflicts with human activities is crucial for the selection of areas where conservation efforts should be maximised. One of the strongest arguments of local people with negative attitudes towards large carnivores is the impact of these species on livestock production (Conover 1998). In the Carpathian region, the predation on domestic animals is mainly due to wolf and bear attacking unguarded livestock that are usually left on mountain fields during summer period, when shepherds set up their camps in the mountain meadows (Mertens and Promberger 2001). The identification of areas of potential conflict can represent a useful tool in management practices and the outputs produced may drive actions such as damage prevention measures or removal of “problem animals”.

The *Carpathian Expedition* was set up in Autumn 2001 to carry out a survey aimed at collecting data on large carnivores presence throughout the Carpathians (see section 5.5.2) for validating the outputs obtained with the Mahalanobis distance (see section 5.5.2.1 for the validation results). The survey was conducted mainly through interviews with local hunters, park administrators, foresters and agriculture producers. The people interviewed were requested to show the locations where they had seen a large carnivore or its tracks in the last year. In addition to this information, an open conversation was set up with the interviewees and a set of questions about damage were asked in order to locate the areas where conflicts between the presence of large carnivores and human activities was highest (Fowler and Mangione 1990). The data gathered were used mainly for validating results of the environmental suitability, but also for identifying areas where conflicts between humans and carnivores were the strongest.

8.3.1 Methods and data used

A total of 114 point locations where conflict was reported was collected through the interviews carried out in the whole Carpathian Region. These were plotted on the environmental suitability map for the three carnivores generated by pooling the outputs of the Mahalanobis distance maps. The proportions of the damage locations included in areas classified by the Mahalanobis distance were reported in order to characterise the areas were major conflicts have occurred in the past.

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[2] Part of this section was published as: Salvatori V. and A. Mertens (2002).

A more intensive study was carried out in a subset of the Carpathians, in order to identify the areas where conflicts were likely to occur, based on knowledge of presence of livestock. The likelihood of damage occurrence was modelled in the Transylvanian area using data of shepherd' camps location and environmental suitability for wolves and bears (fig. 8.2).

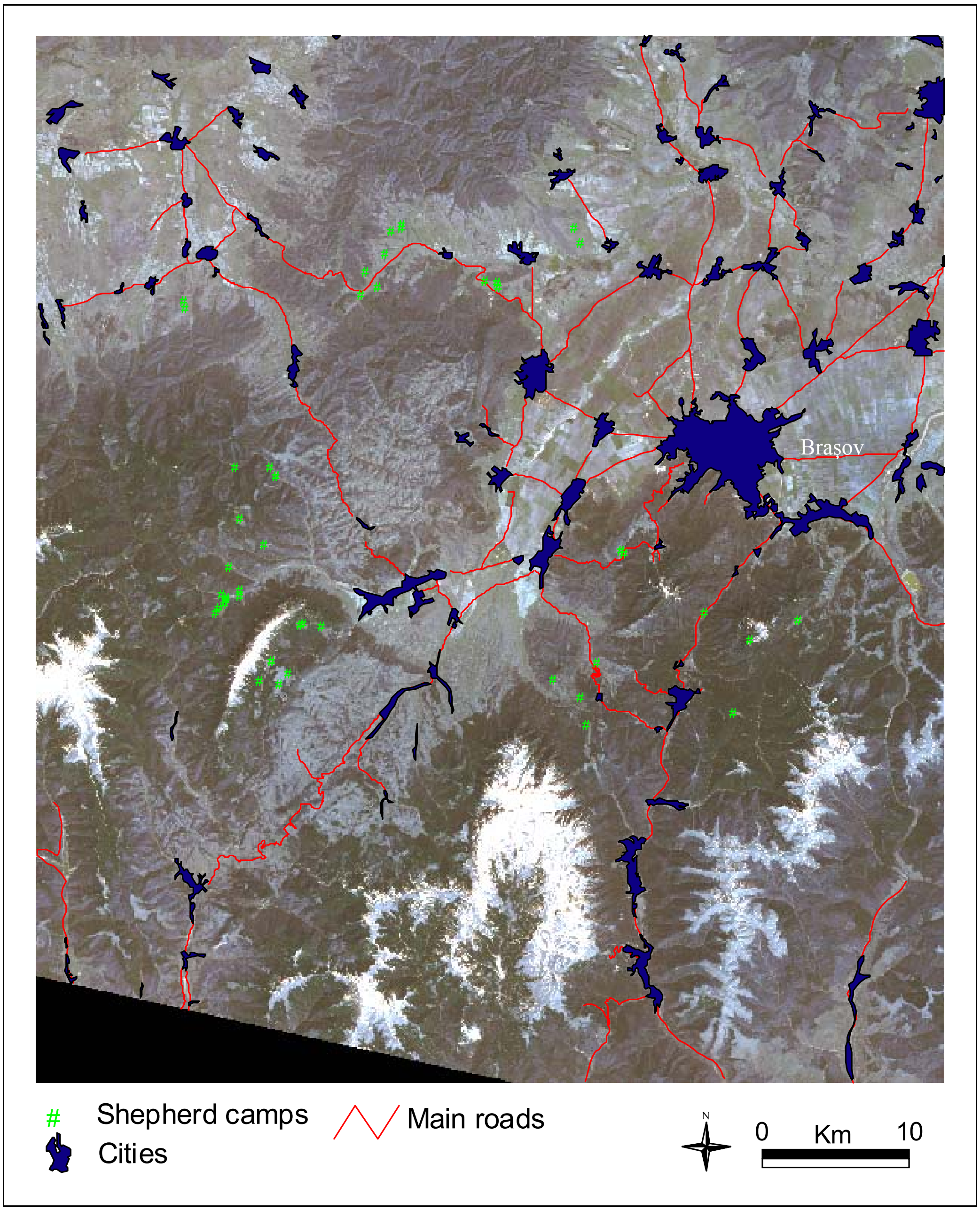

Figure 8.2 – The subset of the study area where likelihood of conflict was mapped using data on location of shepherd camps. The background image is a subset of the Landsat 7 ETM+ satellite image acquired on the 5th of April 2001 (see section 6.2.1.2 for more details).

Data on locations where damage suffered by local people from bear and wolf were used together with the output produced by the Mahalanobis distance for mapping environmental suitability for large carnivores and the suitability for shepherds camps to be set in summer. The methodology used for the scope was the Mahalanobis distance to map the areas suitable for the shepherd camps.

The shepherd's camps were located and monitored in the area by A. Mertens (in prep., CLCP 2001) and the spatial analyses of conflict likelihood were performed entirely by the author to produce a collaboration work (Salvatori and Mertens 2002). A total of 60 shepherd camps were monitored in the grazing period (Summer) during 5 years (Mertens, in prep.). Eighteen of them suffered damage either from wolf or bear. Those were used as test set for validating the results obtained. The remaining 42 camps locations were used as training set for the Mahalanobis distance to estimate the suitability for shepherd camps in the area, with the land cover map obtained from the Landsat 7 image (see chapter 6 for the details of image classification procedure and results obtained). The output was classified into seven classes of environmental suitability for the presence of shepherd camps and subsequently used for estimating the likelihood of conflicts occurring in the areas by combining it with the environmental suitability for wolf and bear. The latter was obtained by combining the outputs for each species in a conservative manner, whereby all the areas that resulted to be highly suitable either for wolf or bear were reclassified as highly suitable. It can be considered as the inverse of the minimum function used previously for pooling the suitability of the three carnivores (see section 5.6):

1	1	1		2	1	1		1	1	1
1	2	2	and	1	1	2	=	1	1	2
1	3	2		2	3	3		1	3	2

Figure 8.3 – The resulting grid from the inverse of the minimum function operation between two grids containing D^2 values would contain the lowest value assumed by each cell in the two input images.

The likelihood of conflicts occurring in the area was obtained by combining the suitability of camps with the suitability for wolf and/or bear through a multiplication operation that required a masking process so that the possible combinations were divided into two groups: classes 1-3 and classes 4-7. This procedure allowed the avoidance of misleading results that could be obtained by combining high suitability value for carnivores with low suitability value for camps and vice versa. The procedure also lowers the number of possible combinations available, making the output classification easier. Table 8.2 reports the classes used for combining the suitability for carnivores with that for shepherd camps and how the output was re-coded.

Camps	wolf_bear	newclass
1,2,3	1	1
1,2,3	2,3	2
4,5	1	3
1	4,5,6	3
4,5	2	4
6	2	5
3	4	5
5,6	3	6
4,5,6	4	6
7	1,2,3,4,5,6,7	7

Table 8.2 – The classification of the output resulting from the combination of the multiplication between the environmental suitability for the shepherd's camps and for the presence of wolf and/or bear.

8.3.2 Results and Discussion

The kind of conflict reported in the interviews throughout the Carpathians was damage to domestic livestock (48%, including mainly sheep, but also horses and cows, and 11% dogs) and agriculture (20% fruit orchards, and 16% beehives). Some cases of attacks on humans were also reported (5% of all damage locations). The damage reported was caused by wolf and bear in the proportions of 44% and 56%, respectively. This does not reflect the total amount of economic loss caused by each species, as the target of the damage inflicted may have a substantially different impact on local economy (i.e., a fruit tree damaged by bear may be a smaller loss than a sheep killed by wolf). The strongly rural-based economy of most of the countries in the Carpathians makes the losses caused by large carnivores highly significant in the local economy. Mertens and Promberger (2001) analysed the economic loss faced by an average shepherd camp in Romania subject to predator damage. The authors found that shepherd camps suffer losses mainly from wolf and bear attacks (59.9% and 39.7%, respectively). They estimated that the impact of carnivore predation could decrease by up to 74% the income generated by an average yearly camp production.

Most of the damage reported occurred in areas of class 1 and 2 environmental suitability for carnivores (29% and 30%, respectively, see also fig. 8.4), while smaller proportions were located in areas of low suitability for predators. In terms of land cover classes, the damage was mainly located in forested areas (52%), most probably in small openings where scattered settlements are present with small fruit orchards or in alpine meadows where sheep are taken for summer grazing. Smaller proportions of the damages occurred in areas of grassland and pastures (25%) and agricultural areas (23%). Considering that the class 1 and 2 areas of suitability for carnivores are composed of forested areas for 79% and 69% of their extent, the results of damage location analysis is not surprising. Nevertheless, it should be noted that the spatial resolution of the land cover data set used (i.e., 250m) may not be able to detect small patches of grassland of alpine meadows in mountain forest openings, that may be used as summer shepherds camps.

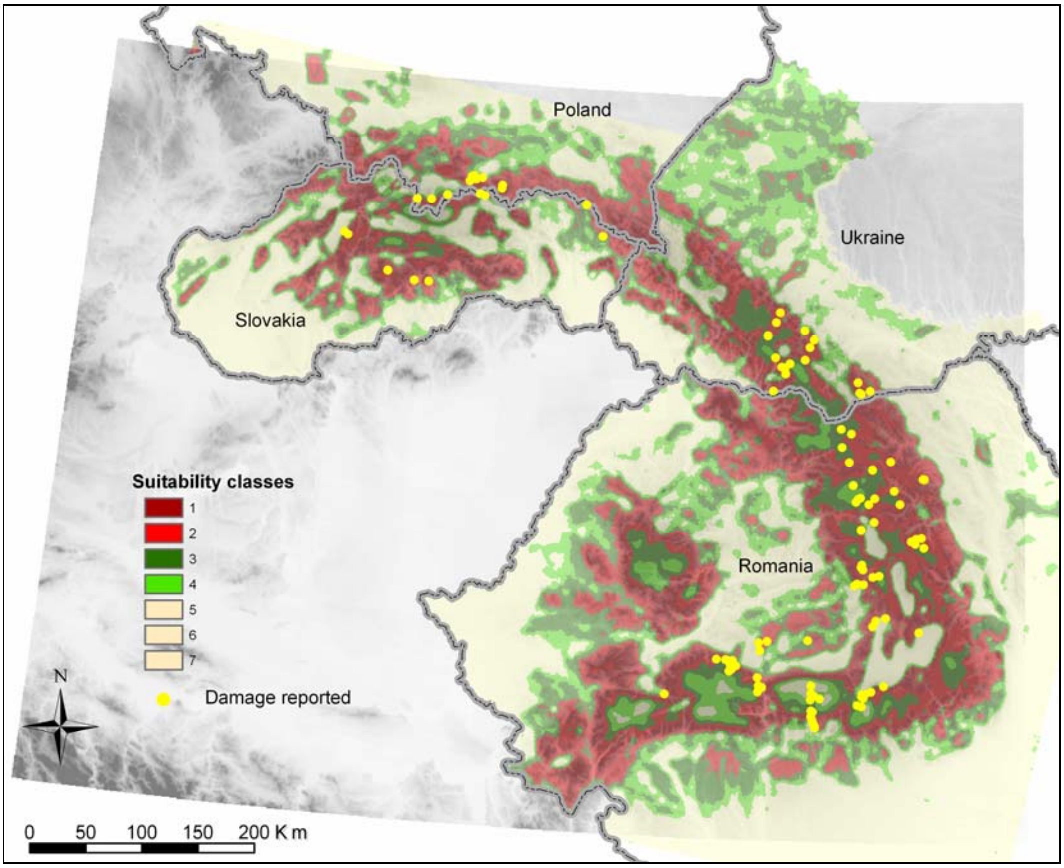

Figure 8.4 – The location of damage reported by the interviewees throughout the Carpathian Mountains, relative to the environmental suitability classes for the three carnivores.

The suitability for shepherd camps in the Transylvania region, around the county (Romanian județ) capital city Braşov, was mainly concentrated in areas of forests and pastures. The training set of camp locations showed that most camps are located in areas of pastures (50%), followed by areas of scattered settlements (21%). This class includes small regions of plateaux where small settlements are scattered among pastures and hay meadows. These proportions are not reflected in the damage data, which are located in the areas of scattered settlements more often than expected ($\chi^2 = 0.59$, $p < 0.01$). These proportions are not consistent with the visual interpretation of the Landsat 7 image, where the areas classified as *scattered settlements* is much smaller and mostly replaced with the classes *transition* and *pastures* (see fig.8.5). Such areas are mainly located in those spaces between the forest outskirts and the agricultural or any other human-dominated lands. It should be remembered that the class *scattered settlements* resulted in the lowest classification accuracy (see section 6.2.1.2 in chapter 6).

The combination of wolf and bear suitability through the inverse of the minimum function maximised the areas of high suitability and minimised the ones of low suitability (fig. 8.6), so that up to 35% of the area was classified as class 1 or 2, and only 7% was classified as class 7. A large portion (86%) of the area classified as highly suitable for either bear or wolf was also classified as having high conflict likelihood.

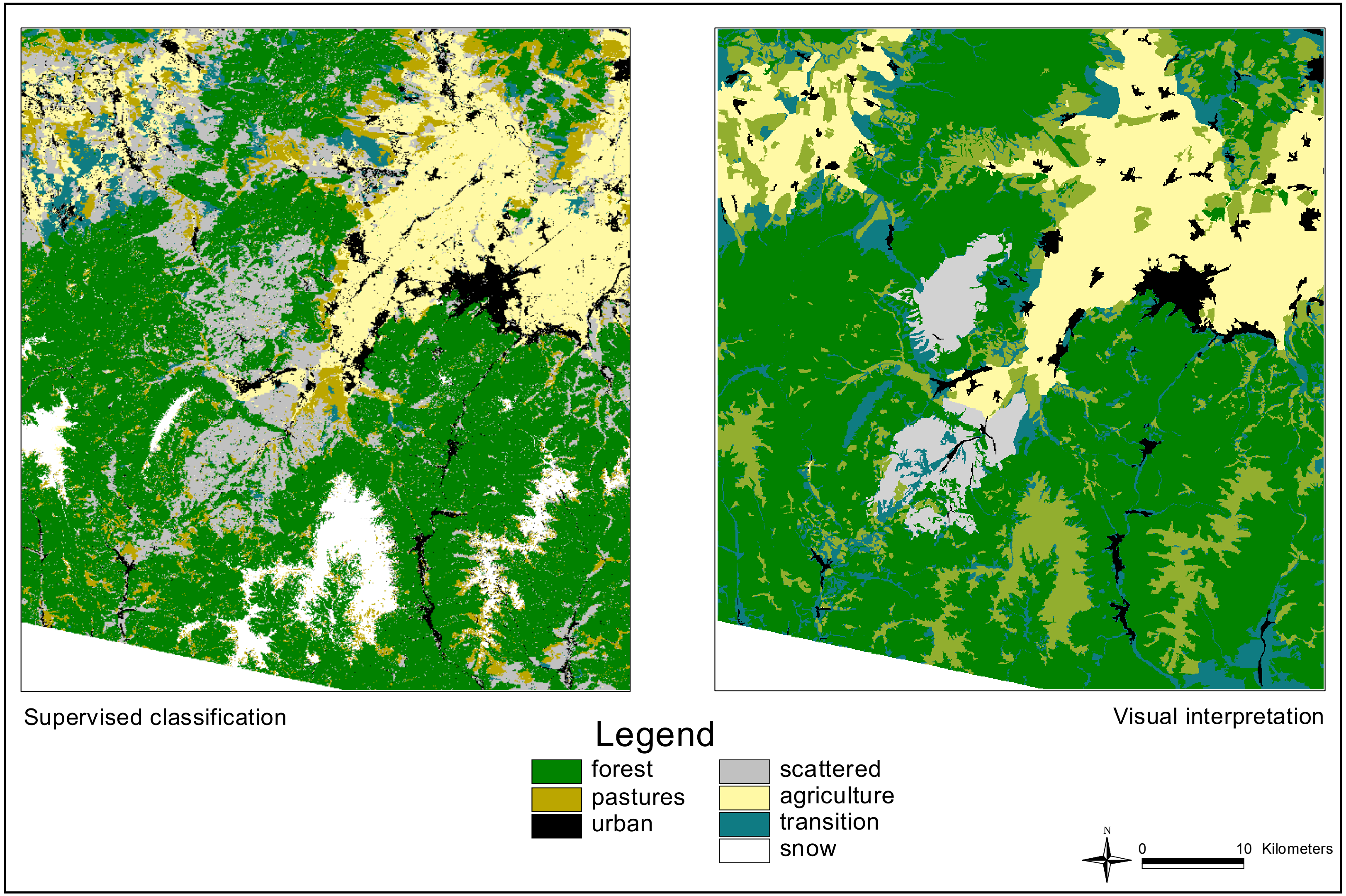

Figure 8.5 – The land cover classes in the Transylvanian region resulting from the supervised classification with a maximum likelihood approach (left) and the visual interpretation (right) of the Landsat 7 ETM+ image.

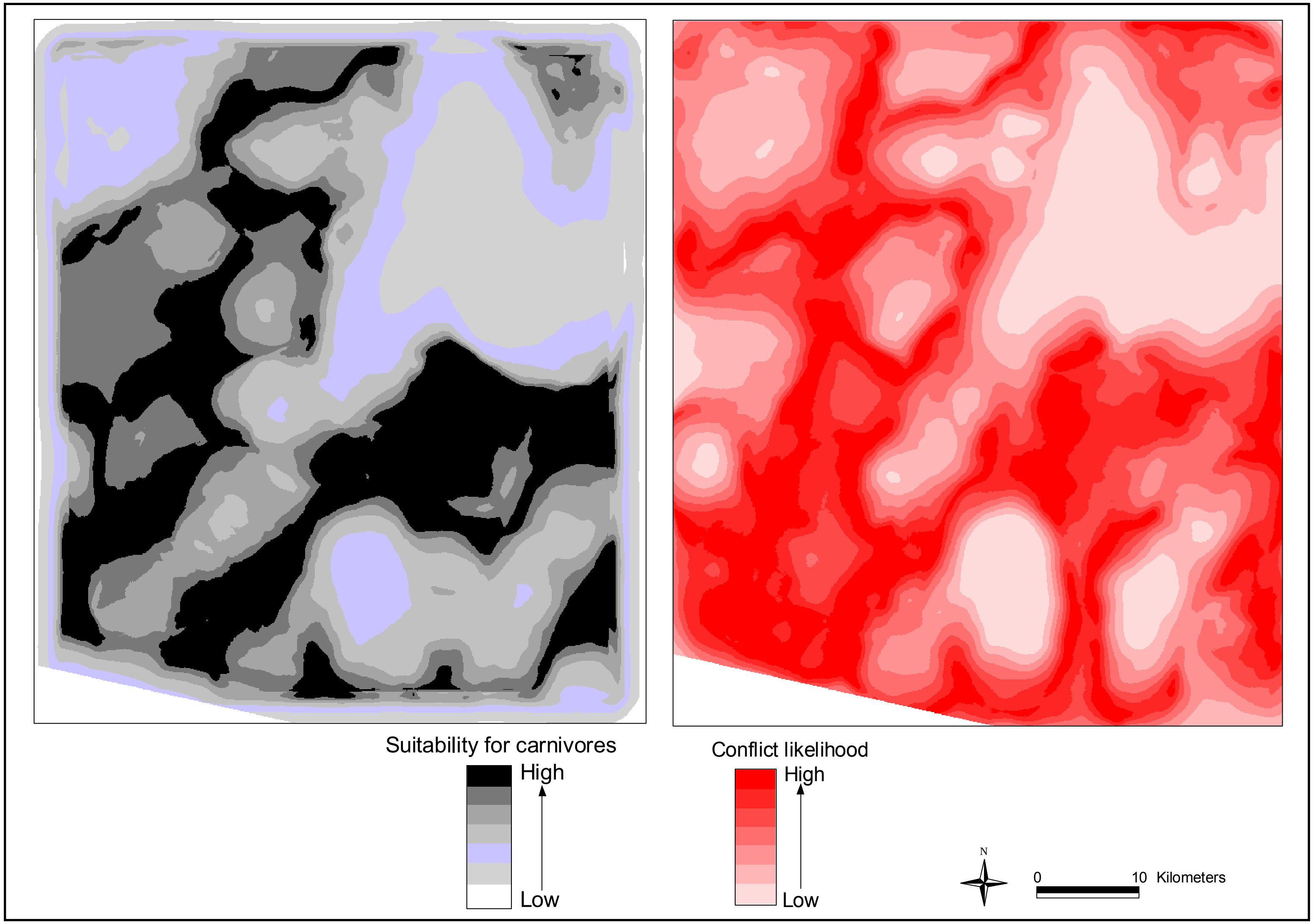

Figure 8.6 – The environmental suitability for wolf and bear (left) in the Transylvanian region and the likelihood of conflicts (right) between carnivore presence and the pastoral activities represented by presence of shepherd camps.

A total of 26% of the whole area was in high potential of conflicts between carnivores and livestock (fig. 8.6). Such areas were mainly characterised by forested areas (84%), pastures in forest openings (6%), and transition land (7%) between forest and human-dominated areas (i.e., either agriculture or scattered settlements) clearly detectable at the spatial resolution of the Landsat 7 image.

The location of potential damage in forested areas is not surprising and the result is consistent with those coming from other parts of Europe. For example, Stahl *et al.* (2002) modelled the probability of lynx depredation on livestock in the French Jura Mountains using variables strongly correlated with damage events, such as size of pasture and distance of pasture from forests and human settlements. The authors found that one of the most significant factors affecting lynx depredation on livestock was the proximity or connection to large patches of forests, presence of abundant natural prey and distance from human settlements (Stahl *et al.* 2002). The results obtained in the analysis run over the Transylvania region appear to be consistent with the findings of the French authors, although an investigation at finer resolution, fed with site-specific data, may be needed to justify analogous conclusions.

The main cause of carnivore damage to human activities is strictly related to the use of suitable areas for the carnivores by humans for economic production (e.g., livestock grazing, berry-picking, fruit cultivation). The reduction of livestock-damage conflict has been developed through two main strategies in Europe: either through zoning, thus separating carnivores areas from human areas; or mitigating conflicts aiming at conserving both in a multi-use landscape (Linnell *et al.* 1996). The complete exclusion of wildlife form human-dominated areas is surprisingly difficult, particularly for highly adaptable species such as wolves and bears. The isolation of carnivores within their environment is particularly difficult when they need large extents, as is the case of the three species targeted here. Such difficulty is increased by the effect of illegal hunting, usually higher at the edge of reserves (Revilla *et al.* 2001), so that the actual area of protected territory is much smaller that the reserve surface. On the other hand, the co-existence of wildlife and humans is matter of international debates and policies (Conover 2002, Council of Europe 2001) because the impossibility to establish large areas to protect calls for integration of the two parties. Methods for decreasing such conflicts have the general objective of preventing damages caused by wildlife. A number of methods, either traditional or innovative, are used for the purpose, but their efficacy appears to be location-, tradition-, and environmental conditions-dependent (Smith *et al.* 2000a, 2000b). In Romania, the long-term existence of large carnivores has made humans keep the habit of protecting their livestock in forested areas, unlikely many of the western European countries that have experienced local extinction of carnivores, consequently losing the habit of protecting sheep flocks (Stahl *et al.* 2002). This situation might be susceptible to drastic changes during the economic development that the countries need to go through in order to join the European Union.

The potential increase of habitat fragmentation may lead to an increase of areas where damage may occur, thus making the conflicts between humans and carnivores worse. In light of these considerations, a stronger effort may be needed to enhance economic sources of local people and letting enough suitable areas for large carnivores where they can feed on their natural prey. This may be done through an integrated management of the land and the setting of a network of protected areas. The latter aspect is one of the objectives of the Natura 2000 programme of the EU (1995), and the Council of Europe currently has a strong interest in establishing an Ecological Network throughout the Carpathians. The following section will treat the issue of protected areas in the Carpathians and their impact on large carnivore conservation.

8.4 Potential effect of protected areas

The conservation of natural environments is an ancient practice that has been done with different goals in various stages of human life on Earth. The set aside of areas where human actions may be restricted started in the last two centuries with the establishment of hunting reserves in colonies of European conquerors. Nowadays, the driving force to environmental conservation is the limitation of the rate of natural environment destruction caused by human activities. The establishment of protected areas is a critical process that has frequently been carried out without objectivity (Margules and Pressey 2000), and efforts towards the establishment of objective procedures to establish priority areas for conservation have been (and still are) made (Myers *et al.* 2000, Margules and Pressey 2000). The urgency to establish procedures for setting conservation priorities to be used for landscape planning is underlined in Europe, where the landscape is highly fragmented and the pressure of human activities is continually increasing.

The consequences of landscape fragmentation are diverse on different ecosystems, and a procedure for conservation planning should include the setting of priority species, habitats, and background knowledge of the actual situation (Margules and Pressey 2000), in order to plan for future actions. In the context of landscape changes such as those that the Eastern European countries are facing, this procedure appears to be extremely important. The trend to land homogenisation (Jongman 1995) in Europe is increasingly posing threats to biodiversity and the planning of protected areas is urgent. This need has been highlighted by the EU through the Natura 2000 programme, which aims at establishing a network of protected areas throughout Europe for protecting biodiversity (EU 1995). In this section, I will present the results from an analysis of the efficacy of the existing protected areas in the Carpathians in terms of inclusion of land that appeared to be highly suitable for the large carnivores.

8.4.1 Methods and Data Used

The suitability map for the three carnivores was generated by pooling the outputs of the Mahalanobis distance classifier (see chapter 5 for operational details). This map was overlaid with a coverage of the protected areas in the Carpathians. The national systems of protected area management in the Carpathian countries does not coincide with the classification proposed by the International Union for Nature Conservation (IUCN), and in some cases the management regimes of areas classified as having the same conservation status vary between countries. Most information on protected area management was difficult if not impossible to obtain, and was mainly published in local languages. For this reason, the protected areas were considered as all having the same effect on large carnivores, limiting both hunting activities and natural habitat destruction.

The map of protected areas in the Carpathians was obtained from the WWF International–coordinated Carpathian Ecoregion Initiative (WWF 2000), which included a working group on the protected areas and produced a map of all protected areas in the Carpathian Mountains. The data were received in digital format in geographic coordinate (lat / long), and were reprojected into the UTM WGS84 coordinate system in order to match the rest of the data set. The map was subsequently converted into a raster image of protected areas and was used for clipping the map of environmental suitability for large carnivores.

A regional analysis was performed in Arc-View 3.2 (ESRI 2002) in order to quantify the proportions of different suitability classes included in the protected areas territory. A threshold of minimum area of suitable habitat was set equal to the mean home ranges for the three carnivores (i.e., 93.8 = average between 82, 59.9, 139.3. See chapter 4 for an extensive explanation on the estimates of the average home range for each species).

8.4.2 Results and Discussion

The system of protected areas in the Carpathians covers a total surface of 22,408 km^2. This figure does not include the areas not covered by the data set considered, but included in the Carpathian Ecoregion (i.e., Eastern Austria, Czech Republic and Hungary). Figure 8.8 shows the overlay of the protected areas on the suitability map for the three carnivores. There it can be seen that the majority of protected areas are located in the northern portion of the Carpathians, in Slovak and Polish territories. Furthermore, some of the Romanian protected areas are currently planned, but not yet established. The portion of the Carpathians included in any kind of protected area (11.8% of the area) appears to include mostly areas of high suitability for large carnivores (see fig. 8.7).

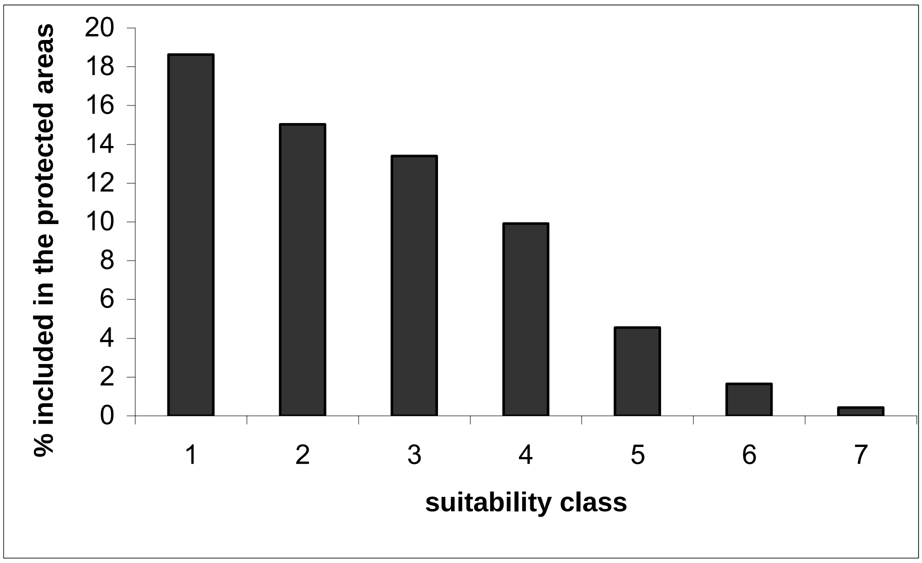

Figure 8.7 – The percentages of areas associated to the suitability classes in the Carpathians that are included in the territories covered by the protected areas.

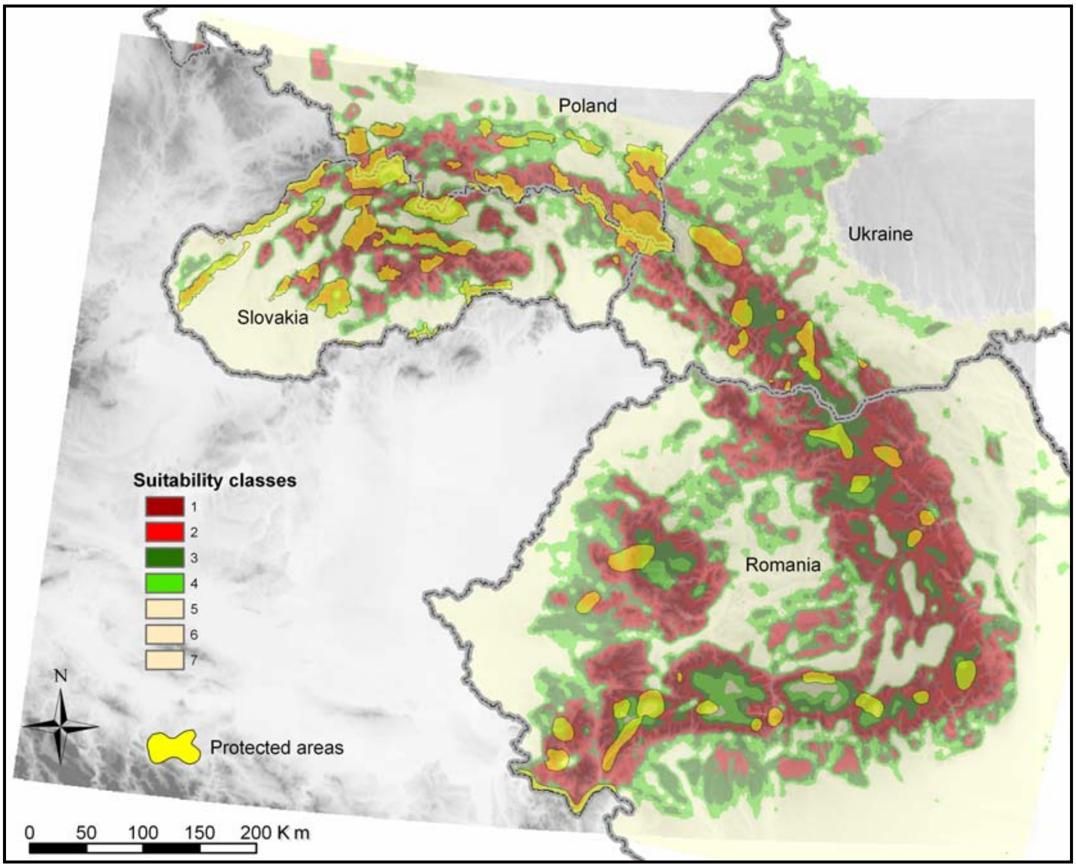

Figure 8.8 – The location of the protected areas in the Carpathians with respect to the environmental suitability map for the three carnivores.

Considering the portion of the Carpathians included in each of the four countries under study (see chapter 3), there appears to be an inverse trend between percentage of Carpathians included and percentage of such territory to be protected. At the two extremes are Poland, with only 9.3% of the Carpathians in its territory, actually protects up to 26.8% if it, and Romania, covering up to 55% of the Carpathians, only protects 5.7% of such territory. Figure 8.9 illustrates the proportion of Carpathian territory contained in each of the four countries considered that is currently included within the territory of the protected areas.

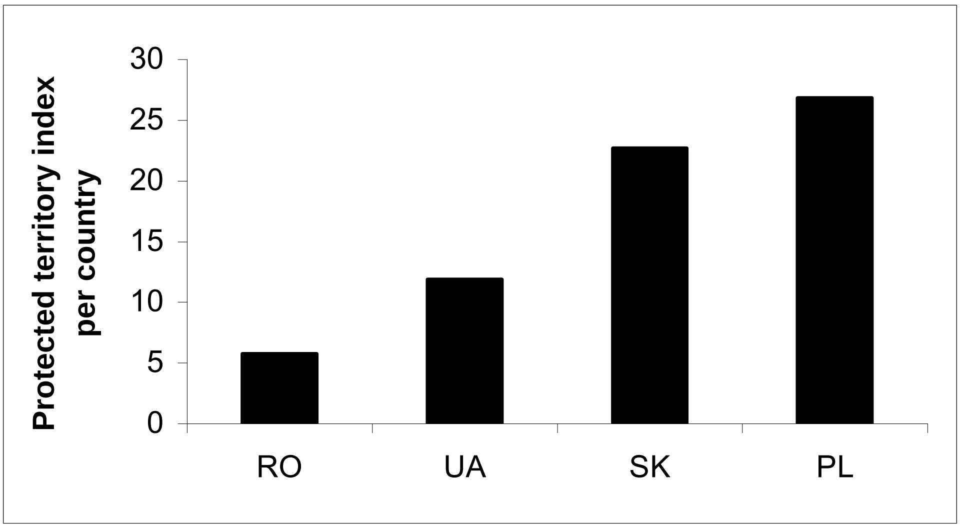

Figure 8.9 – Ratio between the portion of Carpathian territory and the surface of overall protected area in each of the countries considered.

The Romanian position appears even more challenging when looking at the quality of the territory covered by the protected areas, such that the proportions of each suitability class included in the protected areas territory on a per country base is shown in figure 8.10.

From the graph in figure 8.7, there appears to be a general tendency to place protected areas in highly suitable places for the large carnivores, although some countries are currently protecting areas of medium to low suitability. This is particularly true for Poland and Romania. The current position of Romania is favourable for the catalysing action of establishing reserves in ecologically sound areas. A different situation may be found in Ukraine, where the establishment of new protected areas is made very difficult by the dramatic economic situation the country is currently facing.

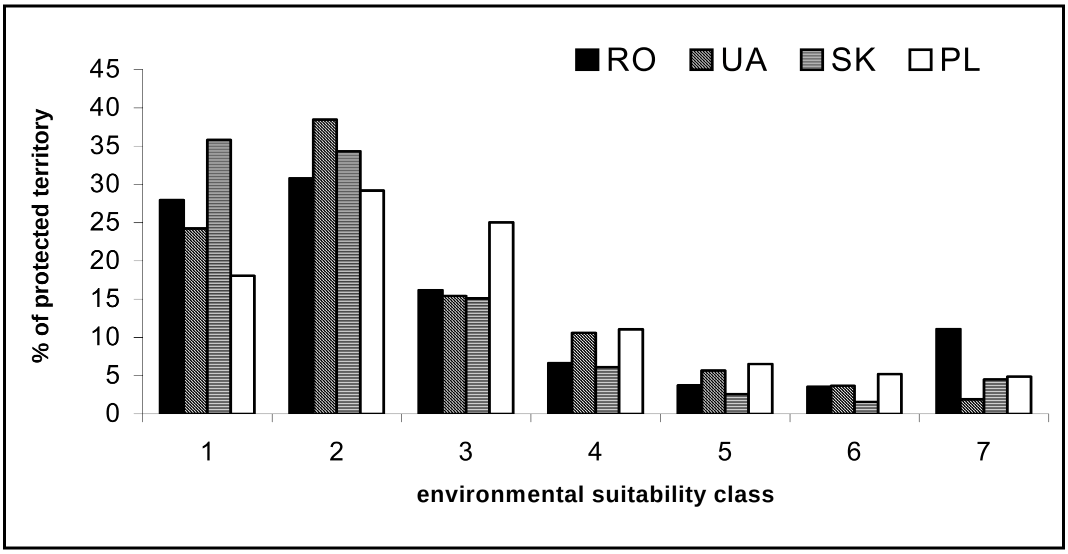

Figure 8.10 – The proportions of environmental suitability classes included in the protected territory of each Carpathian country considered.

Only fifteen out of 68 protected areas include in their territory an area of highly suitable environment at least as large as an average carnivore home range. Pooling the suitability classes one and two, the number of protected areas that contain at least 93.8 km^2 of "suitable" environment goes up to thirty-three. It is notable that 16 protected areas do not include highly suitable environment in their territory at all, and four of them not even include suitability class two. Only 23 protected areas include in their territory areas of suitability class either 1 or 2 as large as two mean home ranges of carnivores. This could be critical for territorial animals like the species considered in this project are.

Most of the Carpathians are highly suitable for carnivores and the small proportion of the territory included in protected area is alarming. Considering that the Carpathians host nearly 1/3 of the European large carnivore population, and that the countries are experiencing a strong economic pressure to be aligned to the standards imposed by the European Union, a major effort should be made towards the identification of those areas that will ensure the effective conservation of such carnivores. It also must be noted that some of the reserves included in the map of protected areas do not have strict prohibitive management, such that in Slovakia, for example, where there are many Landscape Protected Areas where hunting is allowed, thus not offering any protection to wild fauna from the intense hunting activity that exists in the country. Nevertheless, the large number of protected areas in Slovakia makes the country to have a network of protected land that could potentially ensure the conservation of large carnivores. The same cannot be said for Ukraine and Romania, where the proportions of protected territory are very small. Although the conservation of European large carnivores cannot be granted by the presence of protected areas alone, because of the impossibility to preserve large areas of sufficient extent, they may be needed for the hosting source populations in an eventual metapopulation structure that would potentially develop in highly fragmented environments. Nevertheless, an integrated policy for biodiversity conservation should consider both the protection of areas dominated by highly natural environments and the implementation of conflict mitigation measures outside the protected areas (Bennett and Robinson 2001).

8.5 Conclusions

The Carpathian population of large carnivores is one of the most important in Europe, consisting of about 1/3 of all European large carnivores. The identification of areas where conservation effort should be focused appears to be extremely useful in countries where economic pressure is high for the inclusion in the European Union. The traditional management of large carnivores, strongly dominated by hunters rather than ecologists or scientists, can pose serious threats when hunting activities also become a source of income, if the activities are not regulated through legislation and local/regional/national regulations. This is the actual case in some of the Carpathian countries. Although they have all signed the Carpathian Convention, the modification and subsequent implementation of new legislation may require long periods of time, during which the Carpathian population of large carnivores may be exposed to increasing hunting pressure. This is due to the opening of the hunting tourism industry to the western market without having a management strategy based on strong scientific basis. Trophy hunting of large animals may not have detrimental effects on the targeted population if appropriate knowledge on the population structure and density, as well as the environmental resources available is available. These information are usually extremely difficult to produce (Tufto *et al.* 1999).

In addition to this, the strongly rural economy sees human activities expanding and increasingly competing with carnivores for areas currently forested that may be subject to development. Nowadays, the areas inhabited by large carnivores are in high potential conflict with livestock husbandry. The adoption of damage prevention measures in appropriate locations and the payment of damage compensation according to the probability of damage would probably mitigate such conflicts.

The current system of protected areas in the Carpathians does not appear to be sufficient for securing a long-term conservation of the large carnivore populations in the area. Particularly, the distribution of protected territories is not homogeneous throughout the mountain range. Furthermore, the partial inclusion of areas highly suitable for large carnivores suggests that they may function as sources for future population of large carnivores potentially facing environmental fragmentation. The results obtained suggest the location of new protected areas may be guided by the distribution of areas where the three large carnivores live at their best, thus maximising the effort towards conservation of biodiversity.

Finally, the application of the suitability classification for the identification of areas of potential conflicts between livestock and carnivores and the analysis of suitable environment included in the existing protected areas, showed how the modelling process that dominated the present project might represent a valuable contribution to the future management of such an important portion of European wildlife. The hope now is that a combination of improved understanding and improved information will lead to improved management – but extensive experience suggests the path will not be smooth.

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