Habitat suitability modelling of the Brown bear *Ursus arctos* in Croatia and Slovenia using telemetry data

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The real question is not whether machines think, but whether men do?

(B. F. Skinner (1904-1990), *Contingencies of reinforcement*, 1969, p. 288.)

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Abbreviations

AIC: Akaike's Information Criterion

A.S.L.: Altitude from Sea Level

BaH: Bosnia and Herzegovina

CaS: Croatia and Slovenia

CI: Confidence Interval

CLC: CORINE Land Cover

CORINE: Coordination of Information on the Environment

ENFA: Ecological Niche Factor Analysis

GIS: Geographical Information System

GLM: Generalized Linear Models

GPS: Global Positioning System

HS: Habitat Suitability

RS: Remote Sensing

VHF: Very High-Frequency

Abstract

Large carnivores need vast home ranges containing different habitat qualities and are most involved in conflicts with humans; hence the knowledge of their distribution pattern and habitat requirements is of great importance for their conservation. The Brown bear (*Ursus arctos*) has an important role in the people of Croatia and Slovenia's socioeconomic and land use activities, and has been actively managed in the past decades. Developing an understanding of the bear-habitat relationship will improve bear management and will help in the long-term conservation of this population in the Dinaric Mountains, in the face of increasing resource extraction and human activities. In this study, habitat suitability of the Brown bears in Croatia and Slovenia was studies in relation to natural and anthropogenic elements. Using 132,344 GPS locations from telemetry of 43 bears, responses to the land use types, human settlements, supplemental feeding stations (only for Slovenia) and the forest patches was examined. In both countries, bears predominantly were occupying the cohesive forest patches over 5000 hectares and in distances close (<1000 m) to the feeding stations, but in intermediate (1000-2000 m) distances from human disturbance. Measuring the interaction of these elements through habitat suitability modelling, using generalized linear models, probability of bear presence was increasing in distances farther away from cities and villages inside forest landscape in both countries. However, distances to settlements in Croatia did not show an interaction with forest patches, but it Slovenia probability of bear presence was stable in the same interaction. Bear presence was sharply decreasing in distances farther from feeding station inside and outside the forest patches in Slovenia suggesting that this factor must be considered in future bear-habitat studies wherever supplemental feeding is being practiced. Supplemental feeding seems to be an effective way of reducing wildlife conflicts but has showed negative impacts on species biology and behavior. Key recommendations for future conservation include continued and spatially extended monitoring efforts, study the effects of supplemental feeding on bear ecology and piloting the feasibility of recolonization of bears in the Eastern Alps.

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1. Introduction

The conservation of bears and the protection of their habitat will secure landscapes needed for many other species (Servheen et al, 1998). It will also conserve resources needed by local communities, such as watersheds, other wildlife, and local culture. The Brown bear (*Ursus arctos*) once ranged across most of the European continent, but since 1850 has been restricted to few areas (Servheen et al, 1998).

1.1. The Brown bear conservation in the Balkan region

Despite having faced severe anthropogenic pressures (eradication policies, wars, logging, etc.), the Dinaric Mountains contain one of the most important remnant populations of the Brown bear in Europe (Kusak & Huber, 1998; Jerina & Adamic, 2008). Presently, Croatia and Slovenia (hereafter CaS) share a stable population of around 1500 bears (Servheen et al, 1998; Swenson et al, 2000) while adopting different policies for their bear management. In both countries bear hunting is an important social activity and the majority of bears are living in private hunting concessions owned by families or hunter associations (MKPP, 2002; Huber et al, 2008a). In Croatia, bears have long been considered a "Game Species," and around 94% of their permanent habitat is managed by hunting enterprises (Huber et al, 2008a). Slovenia in contrast, after joining the European Union (2004), has recognized the Brown bear as a "Protected Species" (Kaczensky et al, 2004). However, culling and damage control schemes are still being implemented in the hunting units (MKGP, 2002). Different culling quotas for age/sex classes, supplemental feeding policies, and the existence of wildlife passages on highways are the main differences in the bear management of the two countries, which can affect bear behavior and movement (MKGP, 2002; Huber et al, 2008b). Most bears are exposed to hunting pressure, artificial feeding is practiced for reducing human-bear conflicts and finally human access to forested areas is facilitated by a dense network of forest roads and highways (Kusak & Huber, 1998; Kaczensky et al, 2003).

Bears in the Dinaric Mountains are the only viable representative of a natural genetic source closely related to the bear populations in the Central and Western Europe, which have restricted populations in Austria and Italy (Kusak & Huber, 1998; Jerina et al, 2003). The bear population nuclei which inhabits in CaS needs to be treated cohesively and their connections have to be maintained secure to remain viable. Securing connectivity between these populations could be the most effective way of conserving them in the future (Huber et al, 2008a).

According to recent studies (Huber et al, 2008a; Jerina & Adamic, 2008), the bear population and distribution has an increasing trend in CaS and needs proactive conservation measures. The pressure of hunting bears in CaS is of great importance and has been less studied in the region (Jerina et al, *in press.*). Bear habitat is getting more fragmented by the increase of highways and other infrastructures and bears are further exposed to the conflict with humans and vehicle collision. Additionally, the effects of supplemental feeding on the bear behaviour and the distribution has been less studied around the world (Fersterer et al, 2001; Partridge et al, 2001; Gray et al, 2004; Ziegltrum, 2006) and is crucial for management of the species in the region (Jerina et al, 2003; Huber et al, 2008a). Previous bear-habitat studies have generally focused on the effects of different natural attractant and anthropogenic deterrents (Nielsen et al, 2002; Jansson, 2005; Munro et al, 2006; Mertzanis et al, 2008; Belant et al, 2010). In this study a human-driven attractant for bears is evaluated for the first time. The level of trade-off between food availability at these sites and the risk of being hunted is a concept which can enhance the demonstration of bear suitable habitats. All the above mentioned conservation issues magnify the need for a clear vision on the status of bears in CaS and their preferred habitats, as well as analyzing the influence of the elements involved in the bear distribution.

1.2. Habitat suitability modelling in conservation

Species distribution prediction is one of the most important aspects in conservation (Corsi et al., 2000; Hirzel et al, 2001; Pearce & Boyce, 2006). Habitat suitability studies are applicable in various conservation studies including: saving threatened species, human-wildlife interactions and reserve design (Hirzel et al, 2001; Engler et al, 2004; Johnson et al, 2004). Habitat suitability studies are usually defined as using multivariate models in conjunction with GIS methods to create distribution and suitability maps (Guisan & Zimmermann, 2000). Habitat suitability models, therefore attempt to correlate ecological niche elements with species presence and then project the influential factors into the geographical space to create predictive maps of locations with similar conditions. Presence-only records can provide insight into the conservation status of the species, historical or ecological constraint for distribution of them and identification of the critical habitats or corridor bottlenecks. They can also be useful for wildlife managers (Pearce & Boyce, 2006; Lobo et al, 2010).

This approach has been cited by various names such as "niche-based modelling," "ecological niche modelling," "Species distribution modelling," "habitat suitability modelling," "climate envelope modelling," or "space distribution modelling" (Lobo et al, 2010) which in this study the term "Habitat suitability (hereafter HS) modelling" has been used.

Lobo et al, (2010) reviewed 2333 published studies on HS modelling published at the end of 2008 and reported a notable increase in the number of methodological approaches generated on this issue for different types of data. The early works on this method started in the 1980s with the fundamental works by Busby (1986). Since 1995 the rate of published papers on HS studies has increased considerably, which has made this topic attractive to many biologists and conservationists around the world. Although HS models can be a useful part of conservation studies, the scarcity of data and unreliability of the location of absences are constraints in the application of these techniques (Engler et al, 2004). HS studies have been widely used on the Brown bear populations especially in North America (Mace et al, 1996; Nielsen et al, 2002), and are increasingly used in other regions of the world (Jerina et al, 2003; Mertzanis et al, 2008)

1.3. Aims and objectives

The aim of this study is to investigate the bear distribution in two countries exposed to different management practices and measure the bear's preference or avoidance of different environmental variables. Studying the effects of management interventions, such as supplemental feeding or natural landscapes like forest cohesion through HS studies, will increase the understanding of the most suitable habitats and potential areas for future population expansion of the bears. Spatial data from the use of accurate telemetry study, in combination with fine scale remote sensing, and robust statistical analyses, will demonstrate the bears' habitat requirements. Developing an understanding of the bear habitat in this study will improve bear management and will help in the long-term survival of this population in the Dinaric Mountains, in the face of increasing resource extraction and human activities.

When setting species-habitat studies, clear objectives are among the most important stages (Starfield, 1997). The main objectives of this study are:

a) To identify bear suitable habitats in CaS and measure possible differences between the two countries

b) To investigate bear habitat use for different landscape types and examine the influence of infrastructural elements in the bear ecology

c) To identify the impact of supplemental feeding on bear occurrence in Slovenia and its importance on the bear HS evaluation

d) To investigate the performance of presence-only data from telemetry, remote-sensing information and the power of HS models in predicting bear habitats in contrast to empirical data

1.4. Thesis structure

Chapter 2 gives a background on the telemetry studies and its recent developments, and also provides a brief review on the usage of the remote sensing in conservation. HS modelling techniques will be described with notes on the main steps in performing such models in ecology. Also the study site in CaS and efforts in the conservation of bears in each country will be discussed using recent projects on the bear telemetry.

Chapter 3 describes the methodology used in this study, starting with the methods in transferring and compiling data; identification of environmental variables and then extraction of remote sensed data will be explained. Also, methods in generating pseudo-absence, the HS modelling process and model selection will be explained in detail.

Chapter 4 presents the results of this study, leading to the HS model, as well as the response of bears to different environmental variables and the interaction of different environmental and anthropogenic variables in the bear distribution in CaS.

Chapter 5 discusses the results of HS modelling and compares them between the two countries and to other studies elsewhere. The effects of feeding stations and human landscapes, on bear ecology will be discussed in this chapter and the potential application of HS modelling in conservation will be reviewed. Finally, future steps in bear study in CaS, and recommendations for wildlife managers will be mentioned.

2. Background

This study is based on using telemetry data in conjunction with remote sensing and statistical modelling to create HS models; hence here a brief background on each of these methods alongside description of study site and the research background in CaS will be provided.

2.1. Telemetry studies in conservation

Tracking animals with radio-telemetry devices began in the 1960's by the Craighead brothers (Hebblewhite & Haydon, 2010) with the first devices installed on Brown bears in Yellowstone National Park, USA. Since then telemetry studies have made an invaluable contribution in our knowledge of wildlife (Cagnacci et al, 2010a). The telemetry study of bears started in 1981 in Croatia, which was among the first of its kind in Europe (Huber et al, 2008a). These studies started with use of Very High Frequency (VHF) transmitters, which needed a great amount of fieldwork and required getting close to the tagged animals for data gathering (Cagnacci et al, 2010a). VHF studies were heavily biased on observers' presence (non-randomness), disturbance and changes in the behavior of animals, and had low accuracy (Cagnacci et al, 2010a). Later with the adoption of Global Positioning Systems (GPS) technology to telemetry, the mentioned biases were minimized and with the introduction of the Global Navigation Satellite Systems (GNSS), costs of field operations were reduced significantly and telemetry studies revolutionized wildlife study (Tomkiewicz et al, 2010; Urbano et al, 2010). Compared to old-fashioned radio-telemetry devices (VHF collars), GPS collars offer much better spatial resolution, have consistency in data collection, and respond in a broader range of spatial and temporal conditions (Frair et al, 2004; Hebblewhite & Haydon, 2010). GPS collar data is an accurate way of measuring the animal-habitat relationship and when combined with the actual use of resources through remote sensing the environmental variables or use of biosensors, can produce promising results with reasonable costs (Cagnacci et al, 2010b; Gaillard et al, 2010).

Because of the difference in GPS reception in various vegetation and terrain types, GPS collars can be biased toward recording locations in certain habitats (Tomkiewicz et al, 2010). Generally there are two types of potential bias in the GPS collar data, inaccuracy in data and failed location attempts.

Inaccuracy in data, (which is not exclusive to GPS collars) can be the result of short-term studies. Current devices are performing at a fine scale for animal movements. Failed location attempts errors can cause problems in habitat selection studies because unrecorded data are usually skewed toward certain habitats and terrains.

Additionally there are other issues which might be overlooked when working with GPS collars. Most of the methods and extensions used in handling data have not evolved since VHF studies and are very time-consuming (Urbano et al, 2010). Limited battery life, archive memory and the high cost of units are among the other problems of these devices (Hebblewhite & Haydon, 2010; Tomkiewicz et al, 2010). Also, the separation of biologists and conservationists from field observations has been mentioned in some literature a negative feature of GPS telemetry. This can affect the understanding of researchers from the species of concern and can generate irrational hypotheses (Cagnacci et al, 2010b; Hebblewhite & Haydon, 2010).

The background of telemetry studies on the Brown bear goes back to the first efforts in this field. Mainly these studies have linked location data and the associated habitat characteristics; and this project can benefit from the results of a great number of such studies (e.g. Nielsen et al, 2002; Jansson, 2005; Munro et al, 2006; Mertzanis et al, 2008; Belant et al, 2010).

2.2. Remote-sensing and the use of satellite imagery in conservation

In recent years relating presence data with environmental variables has been greatly facilitated by using remotely sensed data, allowing the assessment of the distribution of resources over vast areas often prone toward difficult accessibility or high cost (Corsi et al, 2000; Pearce & Boyce, 2006). Lillesand et al, (2008) describe remote sensing (hereafter RS) as the acquisition of any piece of information about any object or area without direct intervention. The first examples of RS can be identified as early photographs from earth by balloons in 1858. Since then RS has become more technically sophisticated with the use of satellite imagery; it has contributed extensively to the research fields of the natural and the earth sciences (Lillesand et al, 2008). RS also can be helpful in conservation when measuring changes to the natural habitats.

Ecological and biological studies are increasingly using RS technology and the availability of such information is getting more facilitated for users (Urbano et al, 2010). RS technology is especially effective for measuring and implementing wildlife and habitat studies, land use, land use change, and landscape features (Lahoz Manfort, 2008). Also, the identification of patchiness or the connectivity of landscapes are among important factors in HS studies, which can be obtained from RS (Urbano et al, 2010). RS is moving with such speed that its accuracy of land cover identification is getting close to GPS accuracy, which would be extremely useful in GPS collar studies. These ecological variables then can be used in HS modelling.

2.3. Habitat suitability modelling techniques

Many different analytical approaches have been used to model presence-only data. The selection of the most suitable model depends on the quality of data (Pearce & Boyce, 2006). HS modelling techniques can be categorized to four major approaches (Pearce & Boyce, 2006):

a) Profile or envelope methods: These methods give a crude prediction of a species distribution using environmental covariates. Only presence data is used for these models. BIOCLIM (Busby, 1986) and HABITAT (Walker & Cocks, 1991) are examples of this technique. Environmental envelopes attach presence data to a multidimensional envelope within the environmental space. These techniques usually summarize the environmental variables at each presence point. Consequently, they can be greatly biased toward unreliable presence data. This technique can best used when data on presence and environmental variables are scarce.

b) Regression-based models: Pseudo-absences are representing true absences in this method. Generalized linear models (GLM) and generalized additive models (GAM) are most used for such data (Pearce & Boyce, 2006). Other statistical approaches are tree-based or genetic-algorithms methods which have been proven to be less accurate than regression methods. When data quality is higher these techniques are preferred from the previous one and can reveal more information on the data. In GLMs the combination of environmental variables and a linear predictor are attached to the mean of the response variable by using a link function (Guisan & Zimmermann, 2000). By using different link functions, GLM can fit with various distribution patterns such as Gaussian, Poisson, Binomial or Gamma. For binomial responses logit link is usually applied. Selection among regression models highly depends on how the pseudo-absences have been generated or how control data is available (Pearce & Boyce, 2006).

c) 'Used-available' models: These models are more focused on the levels of 'used' habitats rather than the presence or absence, and potentially the habitat can be freely accessed by the species with certain landscapes being more favorable. The difference between this approach and the previous one is minor and sampling schemes are the same. There are four different models for this approach:

- Ecological niche factor analysis (ENFA): This is more similar to the envelope methods and can be applied using Biomapper software. Similar to Principal Component Analysis (PCA), ENFA summarizes all environmental variables into a few uncorrelated factors using "marginality" (direction in which species niche differ from all resources) and "specialization" (direction which maximizes ratio of variance of global distribution to species distribution) factors (Hirzel et al, 2001).
- Case-control logistic regression: where 'used' resources are contrasted with 'random locations' within the area available to the activity of the species. These models are based on contrasting 'used' and 'available' resources and can be interpreted as the probability of occurrence of the species of concern (Keating & Cherry, 2004).
- Logistic regression algorithm: logistic models are used to differentiate between habitat variables of presence and absence data.

d) Modelling abundance: When an abundance of presence data is known, density estimates or other abundance indices can be used to model with regression methods. If data on the proportions of presence or use-available locations are available, these models can perfectly fit the data.

The choice of the most appropriate model depends primarily on the type of response variable (Hirzel & Guisan, 2002). When the response variable is binary (i.e. presence/absence), a combination of multiple regression with binomial distribution and logit link can be used (e.g. GLM), but also ENFA has been widely used in HS models (Hirzel & Guisan, 2002; Mertzanis et al, 2008; Huck et al, 2010). GLM and ENFA are two of the most practiced methods in HS analysis, which differ mainly in their input data: GLM is based on presence/absence, but ENFA uses just presence data (Hirzel, et al, 2001). Both methods are quite robust and produce good results when the quality and quantity of the data is good (Hirzel et al, 2001). In their study Chefaoui & Lobo, (2008) showed that choosing pseudo-absences is a good approach along with GLM when absence data is not available. Profile techniques such as ENFA tend to over-predict species distribution because of lacking the discriminating absences, hence is not favorable (Zaniewski et al, 2002; Engler et al, 2004). However in the study by Hirzel et al, (2001) they showed that ENFA can predict species distribution in a robust way especially in the case of invasive species using virtual data.

According to Chefaoui & Lobo, (2008) group discrimination techniques like GLM, which use presence/absence data are more reliable and have better predicting power than profile techniques (e.g. ENFA), which deal with presence-only data. In our study, use of GLM was favored to ENFA, because of the mentioned reasons and also because it produces more robust results and has better flexibility on data manipulation for each phase of the modelling (Guisan & Zimmermann, 2000). The use of GLM is a highly popular technique in species distribution prediction studies when accompanied with geographical information systems (hereafter GIS; Guisan et al, 2002). There are numerous examples of GLM usage in HS studies (McCullagh & Nelder, 1988; Pereira & Itrami, Thomasma et al, 1991; Bozek & Rahel, 1992; Pearce et al, 1994; Pausas et al, 1995 and many more).

For selecting the most appropriate model, not only statistical methods play an important role, but conceptual decisions are as important, when selecting the environmental variables for the procedure of model selection (Guisan & Zimmermann, 2000). One of the main tasks in HS studies is identifying the most important, measurable, biological needs and other factors which dictate the species distribution such as anthropogenic disturbances (Corsi et al, 2000). Basic needs can be categorized as food, shelter and reproduction sites (Pausas et al, 1995). When using any environmental variables in HS studies we assume that there is a correlation between the basic needs and the environmental variables used (Corsi et al, 2000). Although it might be the case that the environmental variables will influence all the basic needs of a species, simultaneously. Generalist and wide range species (e.g. Brown bear) have a higher variance of the relationship with the environment and a higher number of location data is required to better understand the interaction of the species with its surrounding environment (Corsi et al, 2000).

Storage and analysis of spatial data can be best done in GIS (Bivand et al., 2008). The first HS studies using GIS were in the 1980's (Hodgson et al, 1988), and since then there is a sharp increase in such studies with more species-specific habitat maps (Corsi et al, 2000). The use of GIS has greatly enhanced the power of extrapolating the results of species-environment analysis in a bigger scale (Corsi et al, 2000). The advantage of GIS is in its ability to process a great number of spatial data and therefore the number of variables and predictive scale can increase considerably. GIS can project the multidimensional nature of species and environment, which can result in effective conservation models (Corsi et al, 2000).

2.4. The Brown bear in the Dinaric Mountains

In this section brief information on the characteristics of the Brown bear habitat in the Dinaric Mountains in CaS will be provided. Then a background on the recent GPS collaring projects in CaS, which provided data for this study, will be presented.

2.4.1. Study site

This study focuses on the Brown bear population in the CaS throughout both territories. The bear population in CaS is situated in the Northwestern part of the Dinaric Mountains, which is also connected to small populations in the Austria and Italy, the rest of the Dinaric Mountains to the South, and also to the Pindus Mountains in Greece, which are shared with other Balkan countries like Bosnia and Herzegovina (BaH), Kosovo, Macedonia, Montenegro and Serbia (Fig. 2.1).

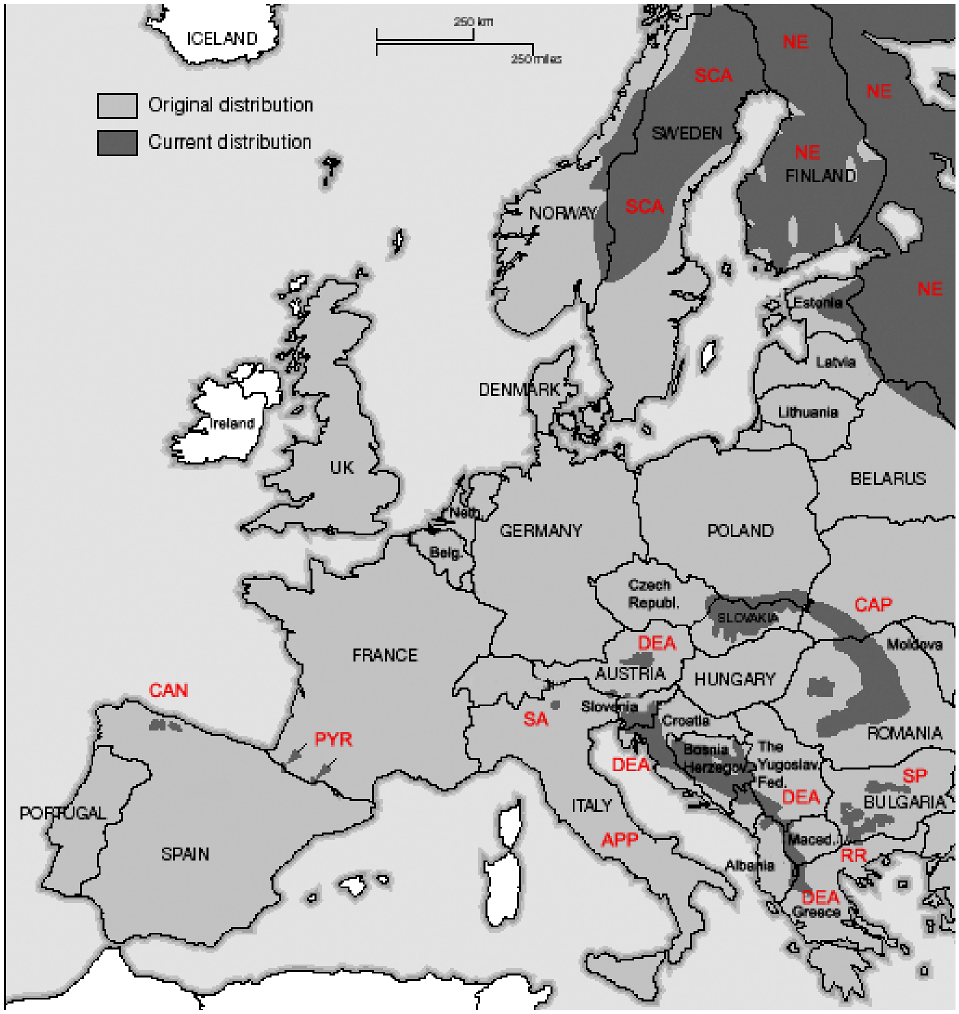

Figure 2.1. Brown bear distribution in Europe with location of different populations APP: Apennines; CAN: Cantabrian; CAP: Carpathians; DEA: Dinaric Eastern Alps; NE: North Eastern; PYR: Pyrenees; RR: Rila-Rhodope; SA: Southern Alps; SCA: Scandinavian; SP: Stara Planina (adopted from Wultsch, 2004)

The Dinaric Mountains are classified as a high Karst region, which is composed of sinkholes, steep gorges, caves, and shallow soil. Elevation in Slovenia ranges from 300 to 1200 m a.s.l. and 0 to 1750 m a.s.l. in Croatia for bear habitats. Annual precipitation averages 1500 mm, and annual temperatures average 7-8 ° C (Huber et al, 2008a; Kaczensky et al, 2003; Kusak et al, 2009). Forest types in bear habitat are from *Abieto-Fagetum-Dinaricum* type, which is dominated by beech (*Fagus silvatica*) and fir (*Abies alba*) with other species like spruce (*Picea abies*), maple (*Acer pseudoplatanus*) and elm (*Ulmus spec.*). Other larger Mammal species in the study area consist of Eurasian lynx (*Lynx lynx*), wolf (*Canis lupus*), wild cat (*Felis sylvestris*), Red fox (*Vulpes vulpes*), badger

(*Meles meles*), Golden jackal (*Canis aereus*), Red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), chamois (*Rupicapra rupicapra*) and wild boar (*Sus scrofa*; Kaczensky et al, 2003).

The human population in Slovenia is just over two million and 4.8 million in Croatia with around 21,300 and 51,300 registered hunters, respectively. The survival of bears despite their disappearance in the rest of the Europe is attributed to the history of protecting bears in the region and the tolerance of people for the presence of bears in their lands. Since the 1890 the Southwestern part of Slovenia (bear core area), which is shared with the Gorski Kotar region of Croatia, has had active management policies on protecting (especially females with cubs), feeding, and hunting bears in the region. As the result of political changes, even this population had fluctuations and in 1940 just around 80 bears were known to survive in Slovenia (MKGP, 2002). Bears the in the rest of CaS were hunted for bounties year-round until 1947 in Croatia and 1992 in Slovenia, when hunting acts were implemented (Huber et al, 2008a). The bear core area in Slovenia is about 348,000 ha. (Appendix 9), which was established since 1966, and most, 80-90%, (Kaczensky et al, 2003) of the bears in Slovenia inhabit the area which borders the Gorski Kotar region of Croatia (Krofel et al, 2010). Bears do not have any barrier or obstacle crossing the border between CaS and freely roam the habitats between these two countries.

The bear population in Slovenia is known to be around 394-475 individuals in about 530,000 hectares of natural landscape (Krofel et al, 2010). The number of bears in Croatia is estimated to be around 1000 animals and is slightly increasing (Huber et al, 2008a). Brown bear is a "Protected Species" in Slovenia (Kaczensky et al, 2004), however culling for the population management of this species takes place. The average annual number of culled bears for Slovenia is around 98 individuals; most (75%) of which are less than 100 kg in weight and are males (83%; Jerina et al, *in press.*). In Croatia the Brown bear is considered a "Game Species" (Huber et al, 2008a). From mortalities of all causes in Croatia from 2000-2007, 71% is related to males, with 75% (85% males) related to legal hunting (Huber et al, 2008a). In Croatia 94.2% of bear permanent habitat falls within hunting units while the rest are located in National Parks where bears are protected year-round. Supplemental feeding takes place in CaS with few dissimilarities in their implementation. The history of feeding stations in Slovenia goes far back to the 1890's when female bears with cubs were fed at these stations and were protected from hunting all year-round. Around 80 to 100 feeding stations have been set up primarily for the bears in the core area in

Slovenia, however bears tend to feed on feeding stations for other wildlife species throughout the country (MKGP, 2002) and the total number of them exceeds 2500 stations. Bear feeding in CaS is rationalized since it keeps bears away from human settlements and agricultural lands and facilitates hunting, and manages the bear population (MKGP, 2002). They have to be at least two kilometers away from any human settlements and one kilometer from farmlands and at least 300 meters from National Park boundaries (last one just in Croatia). A feeding stations is permitted to operate over every 6000-10,000 ha. in Slovenia and 4000 ha. in Croatia (MKGP, 2002; Huber et al, 2008a). Bear supplemental feeding in Croatia started much later, just in the 1970's (Frkovic, et al, 2001). Bear supplemental feeding occurs a maximum of 120 days a year in hunting units with bear hunting permission the following year in Croatia (Huber et al, 2008b). Cereal (corn, oat, and barley), wet fodder and meat are the main supplements for feeding stations in CaS (Huber et al, 2008b). Since 2004, the usage of meat (domestic or wild animal remaining) is forbidden at feeding sites in Slovenia. However, using dead wild animals at feeding sites is occasionally taking place in Slovenia (M. Krofel, *pers. comm.*). The intensity of feeding is higher during hunting seasons (late autumn to late spring), but corn at feeding stations is available to bears and other wildlife throughout the year (Grosse et al, 2003).

2.4.2. GPS collaring bears in Croatia and Slovenia

In this study data on GPS collared bears in CaS were used and a brief background on the methods behind it is provided. In Slovenia bears were captured in an "equal-stratified" design, which is among the most accurate and robust approaches in the prediction of HS and presence/absence (Hirzel & Guisan, 2002). In "equal-stratified" sampling, the study area is first subdivided into environmental classes and equal numbers of plots are randomly chosen and sampled (Hirzel & Guisan, 2002). The application of GPS collars on bears in Slovenia started first in 2005 and more extensively in 2008-2009, using Aldrich leg-hold snares or free-range shooting at feeding sites. In Croatia, the capture of bears was with Aldrich leg-hold snares and was opportunistically at feeding stations. Bears in CaS were captured throughout the country.

All adult animals were fitted with GPS/GSM (global system for mobile communication) collars (Vectronic or Lotek) programmed to attempt a GPS fix every one to two hours (one in Slovenia and two for Croatia), 24-hours a day, with battery life for at least one year. All collars were equipped with different drop-off systems programmed to operate after one year. Data of GPS collars were transferred by SMS (short message service) to computers, but was also retrieved when drop-off function was executed or the bear was found dead. Potential accuracy of GPS-collars was around eight meters.

In Croatia ten bears were captured and fitted with GPS-collars from 2003 to 2009 and 9890 GPS points were collected from these bears. Fix success for GPS collars in Croatia was 45%. In Slovenia 33 bears (Fig. 2.2) were captured from 2005 to 2009 and were fitted with GPS-collars and 122,454 fixes were recorded from these bears. Fix success was around 74% in Slovenia.

Fig. 2.2. A bear fitted with GPS collar in Slovenia. (Photo: Miha Krofel)

2.4.3. Removing biases

There were two potential biases regarding data from GPS-collars in this study:

- Inactivity period of bears: In Slovenia GPS collars were set to turn to 'hibernation' mode when the animals were inactive for more than three hours. This was for saving the battery power of GPS collars. But by not recording locations during inactive periods, there was potentially a loss of data on bear resting sites and the time they spent in certain areas. As a result, all the unrecorded data were replaced with the last point the GPS had recorded a location and the bias was removed in that manner. By comparing the result of this calculation and the original data, the performance was tested and approved (K. Jerina *pers. comm.*).

- GPS reception failure: The above modified dataset of all theoretically recorded fixes have three possible outcomes for locations: 1) fix attempt-successful, 2) fix attempt-unsuccessful, and 3) no fix attempt (this one was rare, and it happened when the collar was not retrieved – mainly due to failed transmission of SMS). Both situations were locations that were not recorded (fix attempt-unsuccessful and no fix attempt) and are not random, and their locations need to be verified. Unsuccessful fix attempt may be the result of topography, vegetation or inappropriate GPS position due to bear activity. For all 'fix attempt-unsuccessful' and 'no fix attempt', virtual locations were calculated using methods in Frair et al, (2004) and Nielson et al, (2009).

To check the error of this approach, this procedure was also done for the known data. The mean error of virtual locations was 300 meters, which is the error for spatial resolution of all further GIS analysis. This process was done only on Slovenian data due to the lack of supplementary data for Croatia.

3. Methods

In this section methods used in this study will be described in detail. Several stages of analyses have been performed in this study (Fig. 3.1.), with a variety of methods including usage of different computer software and packages. Data handling was done in Microsoft Excel 2007 (Microsoft Corp., Santa Rosa, USA), analytical approaches focusing on spatial patterns and the measurement of habitat associations were done using ESRI ArcGIS 9.3 (ESRI, Redlands, USA) along with Hawth's Analysis tools (http://www.spatialecology.com/htools) and Spatial Analyst extension. For statistical computing and graphs R (www.r-project.org) system, a free software environment was utilized (R Development Core Team, 2010).

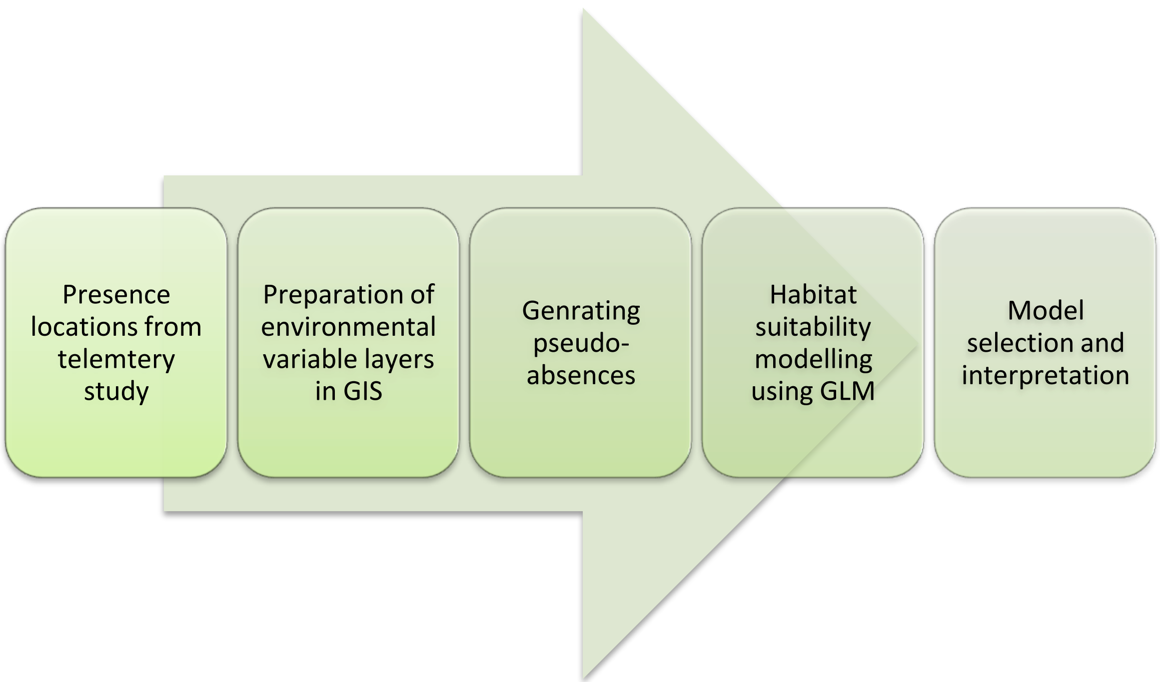

Fig. 3.1. Flow chart summarizing the steps involved in this study.

3.1. Data preparation

Because of differences in the quality and number of environmental variables for each country, the GPS fixes of each country were treated separately and later overlaid with environmental variables of the same country (Appendix 2 and 3). Eight individual bears (ID 1, 2, 16, 17, 20, 25, 29, 31, 32 and 33) from Slovenia had spent times in Croatia, which those data points were removed from Slovenian data and were added to Croatian fixes. Also locations of bears (ID 11, 12 and 19) which were situated in countries other than CaS (Austria and Italy) were removed from the study. In Slovenia the location of three bears (ID: 10, 19 and 27) which were translocated (nuisance bears) was removed from the data. This was because their new habitat was not what they have naturally preferred and may have biased the HS study. Also after translocation some of these individuals showed unusual behavior in their movement (e.g. ID 19 showed long dispersal after translocation and in 43 days recorded a 100% minimum convex polygon of 3800 km^2), which was not representative of bear natural movement patterns. The total number of presence data used in our study for Croatia added up to 13,076 data points and the final data used for Slovenia was 76,772 points (Appendix 5).

3.2. Derivation of environmental variables

In order to identify environmental variables for our study, we considered the basic needs of food, shelter and breeding as most appropriate. Hence requirements like the type of land cover, presence of non-fragmented forests, availability of food in the means of supplemental feeding stations and avoidance from human disturbance through settlements were chosen as candidates of variables influencing bear distribution using previous studies on bears (e.g. Kobler & Adamic, 2000; Jerina et al, 2003; Kindall & Van Manen, 2007).

Land use

CORINE (Coordination of Information on the Environment) Land Cover (CLC) satellite imagery is a European Commission Environment Agency (EEA) programme which produces fine scale images from the landscape. It can be best used in monitoring an ongoing phenomenon on landscape because of its high resolution and constant update. CLC is available for both countries and is freely downloadable (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-changes-clc1990-clc2000-100-m-version-12-2009). Originally CLC had 48 different land cover categories (Appendix 1) however we combined several classes together to have a better understanding of the landscapes used by bears (e.g. Kobler & Adamic, 2000; Basille et al, 2009; Huck et al, 2010). The combined classes were human landscapes, agricultural areas, forests, grasslands, non-vegetated natural areas (beaches, cliffs, glaciers, etc.; hereafter barren lands) and water bodies and wetlands. These variables were converted to categorical responses later in our analysis. CLC from year 2006 with resolution of 100 meters was used in this study (Appendix 6).

Settlements

The settlements vector layer for each country was available for analysis (Appendix 8). Nearest distance to settlements was calculated for each presence-absence data point as a continuous response. Information on settlements in Croatian islands were removed from our analyses because they could have mistakenly chosen as nearest settlements for presence or absence locations while, Croatian islands are not accessible by bears (except Krk island).

Forest patches

Vector polygon layer made from CLC raster image of forest class with areas larger than 5000 hectares (Kobler & Adamic, 2000) were used to filter small fragmented pockets of forest, which are mainly unsuitable as Brown bear habitat (Pazhetnov, 1993). Forest patches were identified for both countries and later split for analysis for each country (Appendix 7). Forest patches layer was transformed to a binary factor of 0’s and 1’s in our modelling procedure.

Feeding stations

Information on the location of all 2545 feeding locations in Slovenia was available (Appendix 9). Feeding stations are generally located in open patches within forests inside hunting units, and are scattered throughout the country (Fig. 3.2). The nearest distance to feeding stations was calculated for each presence-absence data point in Slovenia as a continuous response.


Fig. 3.2. A type of feeding post (left) with the corn container on top and an adjacent shooting stand (right) in Slovenia. (Photos: Arash Ghoddousi)

3.3. Habitat suitability model development

Using statistical models, the effects of variables, which were measured earlier in the probability of presence or absence of bears in the landscape was tested. Statistical methods have the assumption that the population is in stable (equilibrium) in a short time frame and no major stochastic event is affecting the data (Hirzel & Guisan, 2002).

3.3.1. Generating pseudo-absences

When dealing with presence-only data, running regression analysis will be problematic and no model can fit such data (Hengl et al, 2009). To overcome this problem one of the most common methods (Engler et al, 2004; Chefaoui & Lobo, 2008; Jimenez-Valverde et al, 2008) is inserting 'pseudo-absences' which are absences simulated using different methods. Information on absences can be derived from the presence data. Any presence data can be interpreted in this way that a species, at least occasionally, occupied at a certain location. There are two issues regarding generating pseudo-absences as described in Hengl et al, (2009):

- Number of pseudo-absences: The equal number to presence data is usually used for generating pseudo-absences and the statistical theory of model-based designs also supports this idea. We generated the same number as presence data, for each country. All these designs are symmetrical and therefore it is logical to have a spread of similar number of 0's and 1's in space.

- Location of pseudo-absences: As species are normally occupying their preferred habitats we have to generate absences in the least favorite locations. Results of a recent study by Lobo et al, (2010) revealed that absences must be located randomly far from geographical and environmental locations where presences do occur. Here four different methods in generating pseudo-absences can be identified (Chefaoui & Lobo, 2008):

a) Random points across the study area (Kobler & Adamic, 2000; Kindall & Van Manen, 2007)

b) Stratified generation of random points to areas which contain true absence (e.g. Zaniewski et al, 2002)

c) Excluding absences from a buffer around the presence data (Hirzel et al, 2001; Sahlsten et al, 2010)

d) Creating HS maps and generate random points in the least suitable areas (Engler et al, 2004; Chefaoui & Lobo, 2008; Hengl et al, 2009). This approach can best come to application when data on presence is scarce or highly clustered (Hengl et al., 2009).

As this study had a large number of accurate data on the presence of bears in CaS, which is well distributed in most of the study area (Appendix 2 and 3), method 'c' was selected for generating pseudo-absences, which can be better described and has a tighter control over the location of these points in the study area. As mentioned earlier (see '2.4.3. removing biases' section), a buffer of 300 meters around the presence data was selected, which corresponds to our presence data accuracy and pseudo-absences locations were generated in all study area outside these buffers (Appendix 4).

When absence data is reliable, GLM shows the best results and is highly dependent on this (Welsh et al, 1996). Naturally some of these random absences occur in suitable habitats hence it can cause the underestimation of the power of some environmental variables, but meanwhile help spreading locations to all of the study area and will construct a more comprehensive image of species distribution (Hengl et al, 2009).

3.3.2. Data frame

After having the complete data frame of presences and pseudo-absences we can correlate them to environmental variables. The result is a geostatistical point dataset representative of areas of interest with quantitative values attached to each point. The complete data frame consisted of presence and pseudo-absence locations and their position in relation to environmental variables in our study site, land cover types, distances from settlements and feeding stations, and the forest patches. Now GLM can be fitted to the data and interpreting the responses and generating predictions will be possible.

3.3.3. Generalized linear models

Although GIS is a powerful tool for handling spatial data, it lacks enough statistical power for prediction procedures (Guisan & Zimmermann, 2000); hence there should be a link between the statistical models and GIS. GLM has the advantage that it can be easily implemented into GIS, as far as the link function can be calculated (Guisan & Zimmermann, 2000). GLM's can be used when the response variables are binary (Crawley, 2007) and presence/absence data can be treated in that way. The independent variable can be continuous or discrete, and explanatory variables can be quantitative or categorical (factors) in GLM. The 'binomial' family was chosen as the error structure of the data in the modelling is in relation to proportions data (Crawley, 2007). Binary analysis is suitable for situations where at least one of the explanatory variables is continuous (Crawley, 2007). In this case distances from feeding stations and settlements are continuous variables (unique values). The variable weights will be tuned in a way to generate the best fit between model and dataset. GLM is sensitive to quality of data (scenario effect) but not with data quantity (Hirzel et al, 2001). In general fitting a GLM is based on this equation (Hengl et al, 2009):

$$E(\mathbf{P}) = \boldsymbol{\mu} = g^{-1}(\mathbf{q}.\boldsymbol{\beta})$$

Where E(**P**) is expected suitability of occurrence of the species of concern ($P \in [0, 1]$), $\mathbf{q}.\boldsymbol{\beta}$ is the linear regression model and g is the link function. A common link function used for HS studies is logit link function:

$$g(\mu) = \mu^{+} = \ln\left(\frac{\mu}{1-\mu}\right)$$

Therefore GLMs can be identified as a type of logistic regression (Kutner et al, 2004) and dataset should represent a binary response to explanatory variables. GLM models can predict within observed values which in the case of presence and absence is between 0 and 1 (Guisan & Zimmermann, 2000).

3.3.4. Model selection

Model selection is not confined to fitting a model to data but is to generate reliable hypotheses as a priori setting (Burnham & Anderson, 2002). A recent approach in model selection in ecology and evolution is testing different hypotheses simultaneously with data to find the best fitting scenario instead of using the null hypothesis approach (Johnson & Omland, 2004). Because of the need for ecological knowledge in HS studies, it is more appropriate to test and compare the fitness of several models and evaluate their support for different hypotheses rather than running all possible combinations of variables simultaneously (Johnson & Omland, 2004). This is applicable especially when there is more than a single model to choose as the best, different hypotheses are present or when dealing with observational data (Johnson & Omland, 2004). In this study the package 'MuMIn' from R software libraries was used which contains functions for automated model selection and model averaging using Akaike's Information Criterion (hereafter AIC) approaches (Burnham & Anderson, 2002). In this method we can evaluate several competing methods and the package ranks the best fitting model(s) using different techniques. Best fitting models can be filtered through different criterions (e.g. AIC, AICc, AIC weight; Burnham & Anderson, 2002). Also, the average of best fitting models can be calculated in cases when differences between best fitting models are minimal. While using the ranking process and relevant statistical packages are important, one of the most crucial issues in this process is having biologically sound hypotheses in advance (Johnson & Omland, 2004). In this study all variables were chosen in an ecologically sound way and the combination of different variables were chosen only when they could have been described with empirical data or bear ecology. Emphasis was on testing the interaction of natural and anthropogenic elements in our model to evaluating the bear responses in such conditions.

Once each model has been fitted to the data, an AIC, AICc (second-order AIC) and difference between AICc scores (Δ) is calculated for them. The differences in model scores and the best fitting model will then be computed. As in this study the number of observations are more than 40 times the number of explanatory variables, the use of AIC provides promising results. The best fitting model will have the lowest AIC score:

$$AIC = -2\ln[L(\theta_p | y)]+2p$$

(p:count of free parameters, y:data, $L(\theta_p | y)$: Likelihood of the model parameters)

$$\Delta_i = AIC_i - AIC_{min}$$

The likelihood of a model (g_i) then can be calculated as follows when y is the data:

$$L(gi|y) = \exp(-1/2\Delta_i)$$

Also 'MuMIn' package calculates AIC weights and AICc, which show the probability of a model to be the best model for the observed data among 'R' model that they sum to 1:

$$W_i = \frac{\exp(-1/2\Delta i)}{\sum_{j=i}^{R} \exp(-1/2\Delta i)}$$

$$AICc = AIC + \frac{2K(K+1)}{n-K-1}$$

K: the number of estimable parameters n: sample size

Burnham and Anderson (2002) as a rule of thumb have suggested that model supports for delta values between zero and two ($0<\Delta<2$) have substantial empirical support. If there is more than one best-fitting model using different criterions, one of the available methods is averaging across model parameters (Burnham & Anderson, 2002). There are several benefits from averaging models from a practical and logical point of view. In this way, the bias of estimators is often reduced, more precise results can be interpreted, and more stabilized inferences are produced (Burnham & Anderson, 2002). One should note that coefficients produced by model averaging are not comparable to estimate values of each single model and are calculated in a different way: $\hat{\beta}_j$ is an average of all models which x_j appears in (j is not zero):

$$\hat{\beta}\, j = \frac{\sum_{i=1}^{R} WiIj(gi)\hat{\beta}\, j,i}{w+(j)}$$

Ij(gi)={1 if xj is in model gi and 0 if not}

The averaged model consists of a combination of variables in the original models with levels of relative importance calculated for each of them. The "MuMIn" package calculates relative importance factor for averaged models derived from their number of participation in the averaging process.

When a model stands out as the 'Best' fitting model or an average of a few top models, then prediction and evaluation from that model can be used. The extrapolation of selected models for each country was then carried out using values of intercept and slope of each variable within the model. These values were derived from adding the relative estimate value of each variable to the model intercept for categorical variables. For continuous variables estimate value was interpreted as the slope and for interactions, and the value of slopes was added to the slope of initial continuous variable. This way the actual influence of each variable can be better interpreted alongside the usage of degree of significance (*P* value) and confidence intervals (CI).

4. Results

This chapter provides the results obtained from the work flow of developing HS modelling. Starting with the distribution of bear locations within environmental variables, and followed by the procedure of fitting the data to different models and selecting the best-fitting model.

4.1. Brown bear distribution

Overlaid presence/absence data on different layers of environmental variables illustrated the distribution of bear presences and helped in testing the hypotheses for the model selection process. These figures were derived from the raw data without any statistical modelling, but contained important pieces of information regarding bear ecology and distribution, which will help in future stages of this study.

4.1.1. Land use

The presence/absence data was overlaid with the CLC layers and following results were obtained: From the total 13,076 bear locations of the GPS collars in Croatia, 93.5% (12,238 observations) were in the forests. Among the other land use categories, grasslands had 3.7% (489 observations) of the bear presence. But open lands with sparse vegetation (cliffs, beaches, glaciers, etc.) had no bear observations. 1.8% of the points were located in the agricultural landscapes in Croatia. (Fig. 4.1).

Comparable results were obtained from the Slovenian data (Fig. 4.1); from the 76,772 presence locations, 70,641 points (92%) were located in the forests. And 4.2% (3235 locations) of the observations were located in the grasslands and meadows of Slovenia. The next important landscape was the agricultural areas with 3.4% (2675 locations) of the total presence data. Relatively, greater numbers of points (83 points out of 13,076) were located in the wetlands and water bodies in Croatia compared to Slovenia (17 out of 76,772).

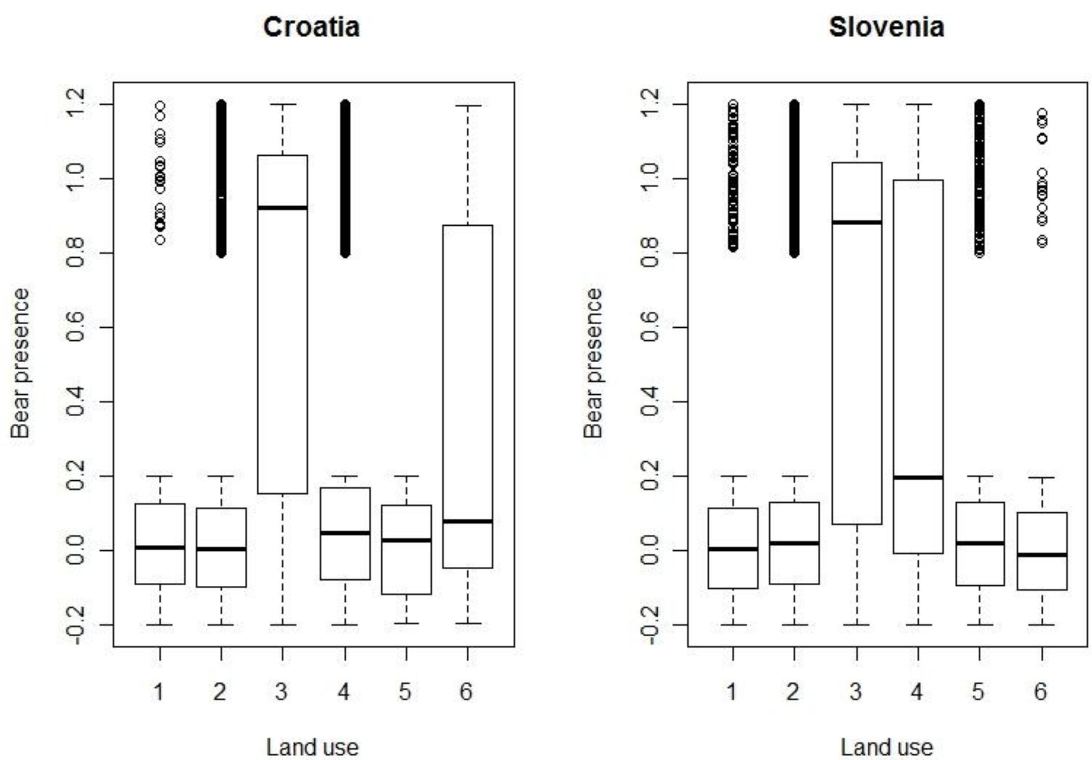

Fig. 4.1. Distribution of bear presence/absence locations in Croatia and Slovenia among the land use categories of CORINE land cover map (Land use categories: 1: human landscape, 2: agriculture, 3: forest, 4: grassland, 5: barren land and 6: wetland and water bodies)

4.1.2. Human settlements

Bear responses to the human settlements in the CaS were following a similar trends (Fig. 4.2.); the probability of bear presence was higher in the intermediate locations (1000 to 3000 meters). However 85.5% of bear locations in Slovenia were farther than 1000 meters from the human vicinity and 70.4% in Croatia for the same distance. Only 11.5% (1506 records) of the bears were located in less than 500 meters from cities and villages in Croatia. There were even a smaller percentage of records for the same range in Slovenia (3%; 2340 locations) despite the larger sample size.

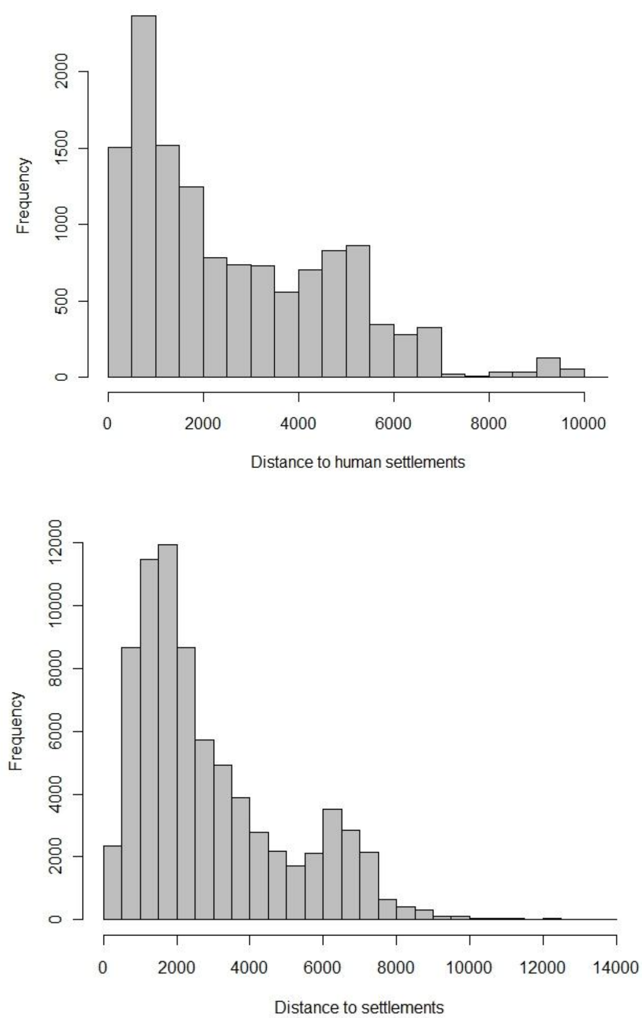

Fig. 4.2. Response of bears to distance from human settlements (in meters) in Croatia (top) and Slovenia (bottom).

4.1.3. Forest patches

The presence of bear locations in the forest patches with areas greater than 5000 hectares was higher than all other landscape types combined. Bears occurred in 70,296 locations (91.5%) in the forest patches in Slovenia and in 12,216 (93.4%) occasions in Croatia (Fig. 4.3). In Croatia, forest patches over 5000 hectares comprised 1,368,297 hectares and in Slovenia 971,099 hectares. By using the forest patches as one of the environmental variables in CaS, 195,894 (12.52%) and 549,733 (36.14%) hectares of fragmented forested areas were removed from the total forest cover, respectively.

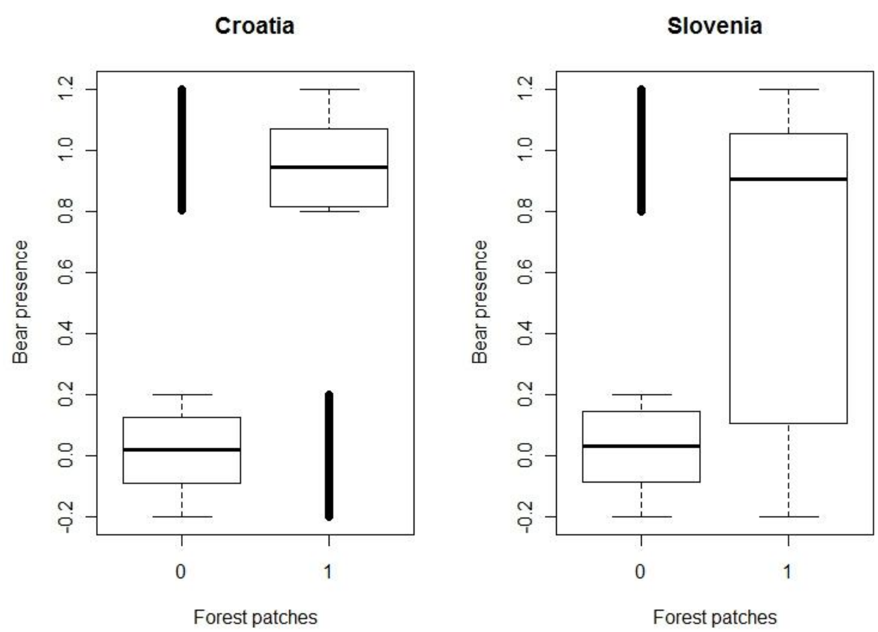

Fig. 4.3. Distribution of bear presences/absence locations in relation to forest patches (0: all other landscapes, 1: forest patches larger than 5000 hectares) in Croatia and Slovenia.

4.1.4. Feeding stations

The nearest distance of bear locations to the feeding stations was calculated for the GPS collared individuals in Slovenia. Over a quarter (26.8%) of the bear locations were found in distances less than 500 meters from the feeding stations (Fig. 4.4). Just less than 1.3% (1032 records) of bears were located in distances over three kilometers from the feeding stations. The result of distances to these locations in Slovenia show that bears are clumped around the feeding stations.

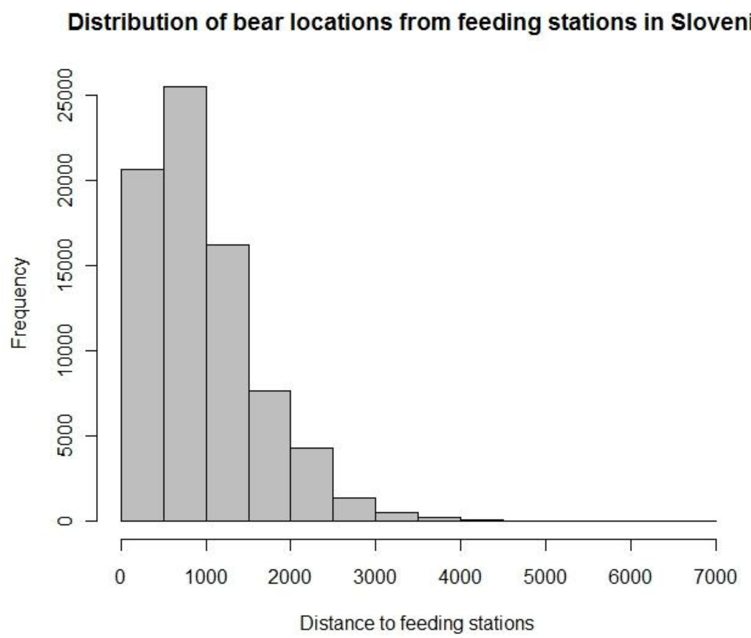

Figure 4.4. Distribution of the bear locations to the nearest feeding stations in Slovenia (distances in meters).

4.2. Model selection

Based on the initial hypotheses and ecologically sound considerations, for Croatian data, forest patches, distance to settlements, land use categories and interaction of distance to settlements to land use, and distance to settlements to forest patches were chosen. For Slovenia, information on feeding stations was available and added to the same variables in the previous model. Also, the interaction of distance to feeding stations and presence/absence of forest patches was included to the Slovenian modelling process.

4.2.1. Croatia

Using the given variables, thirteen different models were identified by "MuMIn" package, evaluated and ranked (table 4.1). Models were ranked using their delta of AICc values (Δ).

Table 4.1. Top nine models ranked using delta of AICc for Croatian data. (K: number of predictor variables; Δ: delta of AICc; *w*: AICc weight; DS: distance to settlements; FP: forest patches; L: land use)

Model ranks	**intercept**	**Model**	**K**	**AICc**	**Δ**	***w***
1	-4.739	DS + FP + L + DS:L	13	21447.28	0	0.730
2	-4.738	DS + FP + L + DS:FP + DS:L	14	21449.27	1.991	0.269
3	-2.979	DS + FP + L + DS:FP	9	21573.05	125.775	<0.001
4	-3.074	DS + FP + L	8	21646.38	199.099	<0.001
5	-3.026	FP + L	7	21888.08	440.799	<0.001
6	-2.566	DS + FP + DS:FP	4	22109.41	662.130	<0.001
7	-2.663	DS + FP	3	22115.35	668.068	<0.001
8	-2.463	FP	2	22417.16	969.882	<0.001
9	-4.572	DS + L + DS:L	12	24642.48	3195.207	0

Since there was not a single best fitting model among the combinations given, less fitting models to the data were filtered, using delta values less than two (Δ<2). Subsequently, the average of the remainder models was estimated (table 4.2). The first two models fit our criteria and were averaged. Distance to settlements, forest patches, land use and combination of distance to settlements and land use show a relative importance of one (100%) and the distance to settlements combination with forest patches had a relative importance of 0.27 (27%).

Table 4.2. Summary of the averaged model for Croatian data. (CI: Confidence interval; SE: Standard error)

Parameter	Parameter estimate	Variance	SE	CI (95%)	
				Lower	Upper
Intercept	-4.73918	0.045898	0.462859	-5.64641	-3.83195
Distance to settlements	0.002127	<0.001	0.000314	0.001512	0.002741
Presence of forest patches	3.996421	0.000285	0.126726	3.748032	4.24481
Agriculture	1.589204	0.050184	0.473305	0.661501	2.516907
Forest	1.566291	0.051985	0.477447	0.630468	2.502114
Grassland	3.378365	0.048779	0.469956	2.457225	4.299504
Barren land	-9.82689	<0.001	130.4723	-265.56	245.9059
Wetlands and water bodies	5.42056	0.082542	0.536005	4.369962	6.471159
Distance to settlements : Presence of forest patches	<0.001	<0.001	<0.001	< -0.001	<0.001
Distance to settlements : Agriculture	-0.00222	<0.001	0.000327	-0.00286	-0.00158
Distance to settlements : Forest	-0.00195	<0.001	0.000317	-0.00257	-0.00133
Distance to settlements : Grassland	-0.00226	<0.001	0.000316	-0.00288	-0.00164
Distance to settlement : Barren land	-0.00213	<0.001	0.040531	-0.08157	0.077316
Distance to settlement : Wetlands and water bodies	-0.00369	<0.001	0.000428	-0.00453	-0.00285

4.2.2. Slovenia

Model selection was executed using "MuMIn" package and 34 models were generated, scored and ranked respectively. A model was found as data best fit to it with delta of AICc (Δ) value difference of over three to the second best model (table 4.3).

Table 4.3. Ten best-fit models ranking using delta of AICc and AICc weights for Slovenian data. (K: number of predictor variables; *w*: AICc weight; DF: distance to feeding stations; DS: distance to settlements; FP: forest patches; L: land use)

Model ranks	**Intercept**	**Model**	**K**	**AICc**	**Δ**	***w***
1	-0.99308	DF + DS+ FP + L + DF:FP + DS:FP + DS:L	16	133715.4	0	0.817
2	-1.055	DF + DS+ FP + L + DS:FP + DS:L	15	133718.4	3.021	0.180
3	-0.98291	DF + DS+ FP + L + DF:FP + DS:L	15	133728.1	12.747	0.001
4	-1.04295	DF + DS+ FP + L + DS:L	14	133730.8	15.441	<0.001
5	-1.01922	DF + DS+ FP + L + DF:FP + DS:FP	11	134055.7	340.340	<0.001
6	-1.13679	DF + DS+ FP + L + DS:FP	10	134076.5	361.091	<0.001
7	-1.03009	DF + DS+ FP + L + DF:FP	10	134082.5	367.131	<0.001
8	-1.17822	DF + DS+ FP + L	9	134114.9	399.523	<0.001
9	-0.73764	DF + DS+ FP + DF:FP + DS:FP	6	135759.5	2044.161	0
10	-0.85807	DF + DS+ FP + DS:FP	5	135806.4	2090.991	0

The calculated AIC for this model was 133,715 with AIC weight of 81.77%. The summary of the model, provided the significance of influence of each variable in this model (table 4.4).

Table 4.4. Summary of the best-fit model for Slovenia. (SE: Standard error)

Parameter	Parameter estimate	SE	z value	*P* value	Significance
Intercept	- 0.993	0.126	-7.855	3.98e-15	***
Distance to feeding stations	- 0.0009897	<0.0001	-51.926	< 0.0001	***
Distance to settlements	0.0001406	<0.0001	1.356	0.175141	
Presence of forest patches	1.826	0.053	33.916	< 0.0001	***
Agriculture	- 0.1381	0.126	-1.092	0.274662	
Forest	0.03327	0.13	0.255	0.798802	
Grassland	1.621	0.133	12.134	< 0.0001	***
Barren land	4.654	0.41	11.325	< 0.0001	***
Wetland and water bodies	0.5976	0.462	1.292	0.196507	
Distance to settlements : Presence of forest patches	<- 0.0001	<0.0001	-3.834	0.000126	***
Distance to feeding stations : Presence of forest patches	<0.0001	<0.0001	2.226	0.025999	*
Distance to settlements : Agriculture	0.0002861	<0.0001	2.719	0.006542	**
Distance to settlements : Forest	0.0003899	<0.0001	3.685	0.000229	***
Distance to settlements : Grassland	0.0001882	<0.0001	1.788	0.073835	.
Distance to settlements : Barren land	- 0.001633	<0.0001	-7.422	<0.0001	***
Distance to settlements : Wetland and water bodies	- 0.001572	<0.0001	-2.498	0.012474	*
P >0.05 , . : P<0.1, * : P <0.05, ** : P <0.01, *** : P<0.001					

4.3. Model interpretation

The process of the interpretation of models was performed using the estimate values driven from the GLM in summary tables and calculating different intercepts and slopes for each interaction (table 4.5).

Table 4.5 Actual intercepts (categorical) and slopes (continuous) estimates for each variable in Croatia and Slovenia derived from GLM results (SE: Standard error).

	Croatia		**Slovenia**	
	Actual estimate/slope	SE	Actual estimate/slope	SE
Intercept	- 4.74	0.462859	- 0.993	0.1264
Distance to feeding stations	NA	NA	- 0.00099	<0.0001
Distance to settlements	0.002127	0.000314	0.000141	0.0001037
Presence of forest patches	- 0.743	0.126726	0.883	0.05383
Agriculture	-3.14998	0.473305	- 0.993	0.1264
Forest	-3.17289	0.477447	- 0.96	0.1305
Grassland	-1.36082	0.469956	0.628	0.1336
Barren land	-14.5661	130.4723	3.66	0.4109
Wetlands and water bodies	0.68138	0.536005	-0.396	0.4627
Distance to settlements : Presence of forest patches	0.00213	<0.0001	<0.0001	<0.0001
Distance to feeding stations : Presence of forest patches	NA	NA	-0.000942	<0.0001
Distance to settlements : Agriculture	<0.0001	0.000327	0.000427	0.0001052
Distance to settlements : Forest	0.000177	0.000317	0.000531	0.0001058
Distance to settlements : Grassland	-0.00013	0.000316	0.000329	0.0001053
Distance to settlements : Barren land	<0.0001	0.040531	-0.00149	0.00022
Distance to settlements : Wetlands and water bodies	-0.00156	0.000428	-0.00143	0.0006291

4.3.1. Croatia

In Croatia the averaged model, the interaction of different land use types and distance to settlements produced different responses (table 4.5). In the forests category, farther distances from human settlements showed positive impact (estimate= 0.0001) on the bear presence. The result of the interaction of distance to settlements with agricultural landscapes and barren lands had minor slopes (estimate= <0.0001) which shows no interaction between these variables and the distance to settlements. Interaction between distance to settlements and grasslands had a negative slope (estimate= -0.00013) which indicates bear presences decrease with further distances in this landscape. Distance to settlement interaction with wetlands and water bodies showed a negative slope (estimate= -0.00156). "MuMIn" package predicted the interaction of distance to settlements and land use to have the highest level of importance (relative importance = 1) because of the involvement of it in all models of the averaged model.

When forest patches interacted with distances to settlements, presence of forest patches had similar slope to absence of forest patches which indicates the parallel response of these categories to distance to settlement (difference<0.0001). Parallel lines are a sign of a lack of interaction between variables. Boosting the distances from settlements, noticeably increased the probability of bear presences in and outside forest patches, but bears are more likely to occupy inside forest patches, (estimate= - 0.743) rather than live outside of them (estimate= - 4.74). By taking into account the unreliable confidence intervals of interaction of distance to settlements and the presence of forest patches (overlapping zero; table 4.2) and low the level of importance (relative importance= 0.27) derived from GLM summary, a less imperative result can be inferred from this interaction.

4.3.2. Slovenia

GLM indicated that the distance to feeding stations has a negative slope when interacting with the presence of forest patches over 5000 hectares (estimate= -0.000942, $P<0.05$). But this slope had little difference with the absence of forest patches (estimate= -0.00099, $P<0.001$) and two responses were almost parallel, hence no interaction between distance from the feeding stations and forest patches can be concluded. However further distances from feeding station has a negative response in the bear presence and probability of presence of bears in forest patches is higher (estimate= 0.883) than out of it (estimate= -0.993).

The interaction of distance to settlements inside forest patches had a slope close to zero (estimate <0.0001, $P<0.001$) but outside forest patches it was increasing the bears' presence chances (estimate = 0.000141, $P>0.05$). This indicates the fact that inside forest patches bears occurrence is not affected by the presence of the human settlements in Croatia, but in other landscapes, farther distances from settlements increases the chance of bear presence.

The interaction of different land use types and distances to settlements provided different responses. In the forests landscape distances from settlements had the sharpest positive slope (estimate =0.000531, $P<0.001$). Distance to settlement slope was also positive for grasslands (estimate = 0.000329, $P<0.1$) and agricultural landscapes (estimate = 0.000427, $P<0.01$). Response in barren lands (estimate = -0.00149, $P<0.001$) and wetlands and water bodies (estimate = -0.00143, $P<0.1$) landscapes to the distance to settlements was negative with almost similar slopes, which indicates these categories did not interact with the latter variable.

5. Discussion

Long term study is needed for a perfect understanding of habitat requirements and the interactions of environmental variables derived from presence data (Gaillard et al, 2010). However, food and other resources are irregularly distributed and use of empirical data from animal presences; one can predict these important elements in animal habitat. Here, first investigations on the potential biases involved in this study are presented and then the influence of each variable in our final model will be discussed. Then the synthesis on optimal requirement for bear habitats, resulting from this study will be presented. Finally recommendations for wildlife managers for the conservation of bears in CaS will be given.

5.1. Model precision

Guisan & Zimmermann, (2000), summarize that when using modelling for species distribution, and measuring suitability of habitat, two assumptions must be taken into account: first equilibrium in environmental conditions (static distribution) and no major stochastic event, secondly sampling must represent a large range of environmental conditions. This HS model is like most other examples and can be biased toward characteristics of the sampled habitats but 'equal-stratified' sampling scheme in capturing bears in Slovenia (which corresponds to majority of the data used in this study) had minimized possibility of such bias. Also there has been no major, measurable stochastic event in the period of sampling and it cannot have considerable effect on the model performance. Anyhow, the use of RS gives a picture of the landscape in a particular given time frame, and the effects of human developments cannot be overlooked in longer time periods. Also historical eradication policies for certain areas (e.g. Krk Island in Croatia and areas outside the bear core area in Slovenia until 1992; MKGP, 2002; Huber et al, 2008a) should be acknowledged which can bias the model or address imprecise estimation of the influence of different variables. The latter issue can cause problems for presence/absence data, as some absences might have been driven by local extinctions and are not true absences, but the model cannot incorporate such assumption to its predictions (Lahoz Manfort, 2008).

Reliability and predictability of HS models depends on the quality and distribution of absences, and environmental variables used and statistical methods fitted to the data (Chefaoui & Lobo, 2008; Lobo et al, 2010). According to Engler et al, (2004) quality (spatial resolution and location accuracy) of data in HS models play a more important role than quantity (number of presences) of them. In this study, the data used was of high precision quality of GPS locations (usually around few meters accuracy in presence data), with short time intervals between data recordings (up to 24 point per day per animal) and with a large number of sampled animals. Also the use of RS was with fine scale (100 meters) accuracy for land use types, which can provide clear insight into the bear distribution in the landscape. Selection of techniques in generating pseudo-absences and statistical approaches was through the most recommended and robust approaches in the literature which all together provide a precise prediction for the model. Extensive effort has been implemented to reduce any bias from this HS modelling, however the potential biases mentioned above should be taken into account when making predictions from the results of the model.

5.2. Response to environmental variables

The influence of different environmental variables involved in HS modelling was evaluated from the final models for each country. Apart from some unexpected responses from a few variables, most of the results were supporting the initial hypotheses behind the inclusion of each variable. However through the modelling, an improved perception of the effects and interaction of each element in bear distribution was provided.

5.2.1. Land use

Bears tend to use different habitats for specific activities namely search for insects and roots in open areas, frugivory in shrublands and sheltering in dense forest landscapes (Munro et al, 2006). In both countries, forests were shown to be the most predominant habitat for bears. Over 90% of bear locations in CaS were located in this landscape. The interaction of forest landscape with distance to settlements showed a positive increase in the probability of bear presence in both countries. This slope was sharpest compared to other land categories in Slovenia, which indicates the importance of forests far from disturbance as bear habitat. In this model forests landscape was comprised of broad-leaved forests, coniferous forests and a mixture of both across CaS. However, in a study in Italian Apennines Mountains Brown bears showed a high preference toward deciduous forest type (Posillico et al, 2004). In a The forest patches variable had more specific characteristics of a bear habitat, being large enough to accommodate bear home ranges. A discussion of the importance of the forests in bear HS will take place in the next section ('5.2.3 Forest patches').

Even though just 3.7% and 4.2% of the bear locations were recorded in grasslands in CaS, respectively, models showed high estimates for this class among other land cover types. Also, the interaction of grasslands and distance to settlements in Slovenia had a positive influence in bear presence. However this interaction was negative for Croatia and no ecologically sound conclusion can be inferred from this response in Croatia. Bears forage on grasses of meadows during summer and it forms an important part of the bear diet in Croatia (Kusak & Huber, 1998). High altitude grasslands can support delayed green-ups, as a determinant of seasonal movement of bears to those areas (Munro et al, 2006). In a study in the Greek Pindos Mountains, bears showed considerable preferences toward open lands (Mertzanis et al, 2008). Also Grosse et al, (2003) reported that ants constitute a major part of bears' diet in Slovenia, however because of the scarcity of open lands (grasslands, forest clear-cut areas), ant distribution is limited. Hence, this can support the hypotheses of the possible importance of grasslands (especially in summer) in our model for Slovenia due to the available food like ants and fresh pasture for bears. Also bears in Slovenia are known to hunt on deer fawns in grasslands in early summer, when newborn animals cannot accompany their mother and are left in the tall grasses (M. Krofel, *pers. comm.*). Grasslands appear to be a seasonal habitat for bears, however because of more human activities and less cover from human encounters, bears are recorded to use grasslands at nights in areas with higher disturbance (M. Krofel, *pers. comm.*). As there is less cover for bears in grasslands, shallower slope of this variable in response to settlements can be interpreted as in this landscape farther distance from settlements will gradually increase the probability of bear presence.

Agricultural areas had intermediate estimates in bear responses in both countries and its results were comparable with grasslands. Bear presences were increasing with further distances from settlements in agricultural landscapes in Slovenia but results from Croatia did not show much differentiation between distances from settlements in this landscape. However, the distribution of bear presences in farms and orchard was not insignificant. Bears have showed preferences in foraging on agricultural fields and orchards when food is available (Mertzanis et al, 2008). However, in Italy bear showed avoidance from vineyard-olive groves (Posillico et al, 2004) and further investigation with finer scale on this feature of habitat selection is needed in future. Higher level of disturbance in this land use type, can explain the shallower slope of bears presence in comparison to grasslands when moving away from the settlements.

Areas near wetlands and water bodies had a very small number of bear locations in both countries; however this number was higher in Croatian data. By further investigation, it became clear that the home range of an individual bear in Croatia overlapped a riverine system and because of the smaller data set in Croatia, it made a slight bias toward the higher percentage of the bear locations in wetlands and water bodies compared to Slovenia. The study of the relationship of bears and surface water showed different responses, in the Brown bear range which might be reflective of the generalist and omnivorous behavior of this species. Bears showed no preference in mire areas in a study of GPS collared bears in Sweden (Jansson, 2005). But preference for areas near surface water has been reported in studies in North America and in Greece (Mertzanis et al, 2008). One of the distinctive features of the Karst geological phenomenon, which is the main type for most of CaS, is that water run-offs like lakes and rivers rarely are formed (Kaczensky et al, 2006). Previous study on bear habitat quality in Croatia did not associate bear habitat with water resources (Kusak & Huber, 1998). In both countries when interacting with distances to settlements, bear presence had a negative trend, which is not a logical conclusion. It can be inferred this happens because of the low number of presence data, and it can be excluded from bear suitable habitats in CaS.

The barren lands category consisted of beach, dunes, sands, bare rocks, sparsely vegetated areas, burnt areas and glaciers. No bear presence was found in this landscape in Croatia and the number of records in Slovenia was 117 locations, which can correspond to bear habitats in the Julian Alps of Northwestern Slovenia, where it is more comprised of cliffs and glaciers compared to the Dinaric Mountains in the rest of Slovenia and Croatia. Response of bears' location in Slovenia in this landscape to distance from settlements was negative which removes these areas as potential bear habitats.

5.2.2. Human settlements

The distance to settlements was increased the chance of bear presence in different landscapes when there were a number of observation records available for that category (forests, grasslands and agricultural areas). Distance to settlements showed the sharpest increase when interacted with forest landscape in both countries, which indicates the importance of undisturbed suitable habitats as prime bear areas. However, when interacted with forest patches in Croatia there was not much interaction between variables and both categories were showing an increasing slope with less reliable results for the presence of forest patches type due to CI overlapping zero. In Slovenia, the presence of forest patches did not change the chance of bear presence (slope close to zero) but the slope was increasing outside of forest patches. It can be concluded that for Slovenian data distances to settlements in forest patches is not influencing bear presence much, but this can increase the probability of bear presence in all landscapes outside of forest patches. In Slovenia, the responses can illustrate that in areas far enough from settlements outside forest patches, the chance of the presence of bears will be similar to inside forest patches. Empirical data supports this hypothesis that bears can be closer to settlements inside forest patches where there is enough cover for them than outside forests. Distance to settlements usually has a non-linear response among different species and after certain threshold animal presences can decrease again. This threshold can be at higher in grasslands than in forested areas. This can also because in CaS, human settlements are scattered throughout the country and far distances from settlements are not available. Population density even in Menisija in Slovenia (bear core area) and Gorski Kotar region (main bear habitat) of Croatia is around 42 and 27 inhabitants per square kilometers respectively and all bears are exposed to the negative impacts from human presence (Kaczensky et al, 2006). Kaczensky et al, (2006) suggest that bears' nocturnal behavior in CaS is result of disturbance from humans through decades of persecution, and in North America they appear to be largely diurnal. A previous study on bears in Slovenia had revealed the importance of distance to settlements as one of the main factors in optimal and maximal habitat of bears (Jerina et al, 2003). Kobler & Adamic, (2000) bear modelling in Slovenia also revealed that bears prefer distances further away from settlements and if they are found near settlements, tend to be more selective on the forest types. Posillico et al, (2004) showed that Brown bears highly avoided the human settlements. In Greece bears showed a behavior of attract and avoidance to human settlements. They avoided human settlements but preferred to get as close at about one kilometer where orchards and cultivated lands occur (Mertzanis et al, 2008). This magnifies the key role of seasonal food resources in bear ecology. Male Brown bears in Norway, showed less tolerance toward human settlements and selected their wintering dens in distances farther from occupied houses and roads (Elfstrom & Swenson, 2009). Bears in Slovenia did not use any cave less than

500 meters from villages (Petram et al, 2004) but human influence showed little impact on bear den site selection in general in both countries (Huber & Roth, 1997; Petram et al, 2004). Pierce & Van Daele (2006) investigated the use of rubbish dumps in Grizzly bears in Alaska on rubbish dumps and concluded that they played an important role in bear diet and some individuals regularly return to these sites.

However, bears' responses to human landscapes is relatively complex. There are attractive food source elements for bears in cities and villages with rubbish dumps, slaughter houses or farms and orchards, which can easily attract bears. However, the disturbance from human presence and its threats and the danger of roads and protective measures like barriers, usually keep bears away from these areas.

5.2.3. Forest patches

Forests provide a great variety of food sources and cover for the Brown bears and are considered as the main habitat for them throughout the world (Servheen et al, 1998). As models cannot recognize the effects of fragmented forests as unsuitable bear habitat, filtering patches of forest less than minimal bear habitat had resulted in more realistic results in HS studies (Kobler & Adamic, 2000; Jerina et al, 2003). The idea of forest patches of over 5000 hectares was first suggested by Kobler & Adamic, (2000) and later Jerina et al, (2003) implemented the same factor and received increase in precision of their results of HS modelling. In our study, the number of bear presences in forest patches was almost similar to all presence locations in forest landscape despite the smaller size of the former. This clearly indicates that bears have preferences in forests large enough to provide them with their ecological requirements. Although forest patches did not interact with distance to settlements in the Croatian model, but the presence of forest patches showed a higher probability of bear presence compared to areas outside forest patches. In Slovenia, these variables had interaction and bear presence was increasing outside forest patches, but interaction with presence of forest patches had insignificant slope. However, presence of forest patches had higher estimates than all other landscapes combined. The interaction of forest patches and feeding stations in Slovenia revealed not much of an interaction, but clearly estimates for bear presence inside forest patches was higher than outside of it. In a previous study in Slovenia, although 88% of bear habitat was defined as in forests but just 33% of the forests were considered as suitable (Kobler & Adamic, 2000). This is comparable to results of this study that bear presences in forests is almost limited to large enough forest patches which are considerably less available. Different results in the area of forest patches in this study compared to previous study (Kobler & Adamic, 2000) can be driven by the higher accuracy of RS sources, the increase in the forest cover in Slovenia, or spatial errors in calculation.

The importance of forest patches indicate that even in the core area in Slovenia, just 66% of forests were suitable for bears (Kobler & Adamic, 2000). However, forest coverage in Slovenia has had an increasing trend from 36% in 1875 to 55% in 1997 (Kaczensky et al, 2003). Forest cohesion was showed to have an important role in the distribution of American Black bears along with a mixture of forest-farm landscape (Kindall & Van Manen, 2007). Only selective logging is allowed in most of the study area in CaS which is not reducing the area of forests but results in a dense network of forest roads (1.5-2.0 km roads per km^2 of forest) and disturbance in the entire habitat. The model estimates for the influence of forest patches in both countries were strongly positive compared to all other landscapes combined, hence showing the importance of this variable in the bear HS study.

5.2.4. Feeding stations

The effect of supplemental feeding on bear distribution was only examined in the model for Slovenia as the data on feeding stations in Croatia was incomplete. To our knowledge, the influence of supplemental feeding on Brown bear distribution has been investigated for the first time, with this study. Bears showed high concentrations around the feeding stations (Fig. 5.1), and the model estimates showed strong negative slopes for distances farther from these sites. However the slope was more negative in areas outside forest patches than inside forest patches which indicate the interaction of faraway distances from feeding stations and locations outside forest patches is an unsuitable combination for bears. However, response to feeding stations can vary among different individuals of bears (M. Krofel, *pers. comm.*). Supplemental feeding of Brown bears have been less practiced throughout its range and only a few studies on the American Black bear have investigated the effects of this intervention on bear ecology (Fersterer et al, 2001; Partridge et al, 2001; Gray et al, 2004; Ziegltrum, 2006). In CaS, their supplemental feeding is one of the controversial topics in bear management, with different views from biologists, conservationists, hunters, and government officials.

Feeding stations are an effective method in facilitating bear hunting in CaS and also have shown their positive impact on keeping bears away from human landscapes and increasing population carrying capacity (Huber et al, 2008b). However their effect on the reproduction of bears has been rejected in a study in Croatia (Frkovic et al, 2001). Supplemental feeding has shown to be an effective and cost-efficient way of reducing American Black bear damage to commercial forest communities in certain seasons in Western Washington, USA (Ziegltrum, 2006). On the other hand, feeding stations can cause damages to forest communities because of the high concentration of wildlife around them (Sahlsten et al, 2010). Huber et al, (2008a) report damages from bears to trees by peeling the out bark of over 1000 trees since 2001 which has an increasing rate. This has been suspected to be one of the effects of feeding stations, as dominant bears do not tolerate others at the same feeding stations and the stress of such interactions cause forest damage from young bears. Eventually, they continue with this behavior on the other trees in the forest. More female bears with cubs were observed farther from feeding stations than in close proximity to them by Frkovic et al, (2001), suggesting that feeding stations do not affect bear reproduction. But this matter can be result of the threat from other bears, which forces female bears to not risk cubs' lives near these stations (Fersterer et al, 2001). This has been proven to be the same response for female American back bears with cubs in Washington, USA (Fersterer et al, 2001). Sahlsten et al, (2010) had predicted that feeding stations can be occupied by a few dominant individuals and increase the chances of inter-population conflicts. Up to eighteen American Black bears have been reported using a feeding station in Washington, USA (Fersterer et al, 2001). Younger bears tend to appear at the feeding sites during the day time which can correspond to the dominance of older bears on these sites at night (Kaczensky et al, 2006). This can cause the habituation of younger bears to human encounters and could result in problematic behavior among young individuals, which are usually more involved in human-bear interactions (Kaczensky et al, 2006). As bears appear in small groups (female with cubs, several males or siblings) the effects of hunting on feeding stations can result in more shy and nocturnal behavior of bears as advocated by Kaczensky et al, (2006). Feeding stations have been proved to the affect movement and habitat choice of wildlife (Sahlsten, et al, 2010). Fersterer et al, (2001) studied the American Black bear home ranges in proximity and distance from feeding stations; home range sizes had no significant difference among these treatments, but during the supplemental feeding season their home ranges were reduced in areas adjacent to these stations, which can result in higher conflicts among individuals. Also feeding sites have been identified as one of the causes of diseases in some species because of the concentration of multiple species and individuals at certain locations (Cross, et al, 2010). The daily fat content in the diet of American Black bears exposed to supplemental feeding in Washington, USA, was over ten times of bears without this treatment, and this can highly influence the ecology and behaviour of the species (Partridge et al, 2001). Supplemental feeding can also deter the life cycle of bears as they might have lighter natural hibernation in winter and make them prone to more conflicts with human and dependency on feeding stations throughout the year.

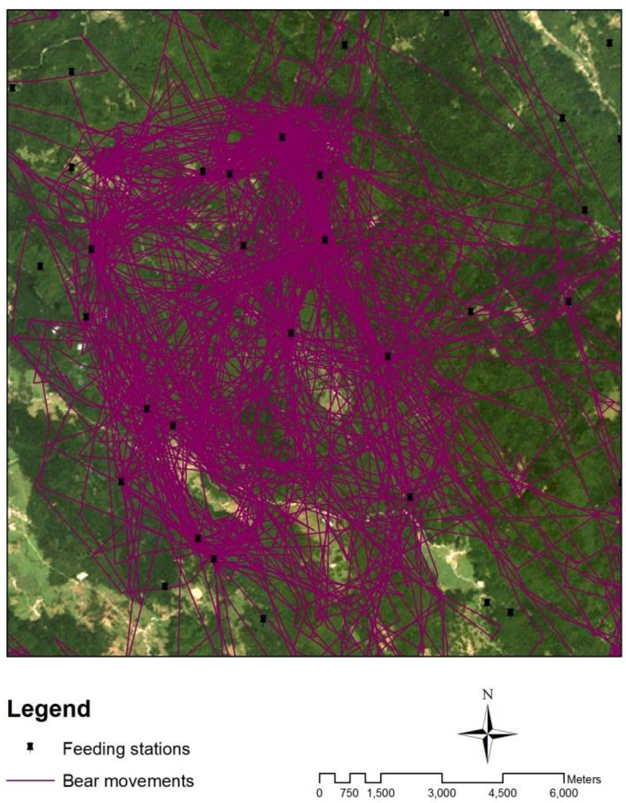

Fig. 5.1. Combined movements of three male bears around the feeding stations in Slovenia

Bern convention on the conservation of European Wildlife and Natural Habitats, recommendations on the Action plan of bear conservation in Croatia, urges abandoning any artificial feeding which makes bears habituated to humans or food. Fersterer et al, (2001) suggests that efficiency of feeding stations declines with population increase. In increasing populations of bears in CaS and the expansion in their distributions, the efficiency of supplemental feeding on reducing damage and conflicts should be monitored. If supplemental feeding affects the population dynamics, changes to its' regulations should be considered in a way to have the least impact on bear ecology and survival.

5.3. Extrapolation of habitat suitability model

In this study, the effects of variables involved in the modelling procedure were supporting empirical data on bear ecology. Through using a large number of precise presence locations in this study, for the first time, the importance of feeding stations in bear HS and distribution was demonstrated. This factor when tested with Slovenian data, showed a great influence on the model with forest patches. Responses of other variables between the two countries in most cases were following the same traits and other studies, emphasizing the importance of forest cohesion and distances to settlements. Also the importance of grasslands and agricultural lands as seasonal sources of food for bears has been identified through this study. This study shows that the availability of food and large enough habitats in combination with habitats far enough from disturbance are factors interacting in bear presence. Differences in response of bears in forests and forest patches toward distance to human settlements is unclear but can interpreted as in large pockets of forests, human disturbance is less influencing bear presence than in all forested areas which are less suitable for bears.

Jerina et al, (2003) in a habitat modelling concluded that bear presence in Slovenia is more dependent on dense forest covers than food availability. However, in their study the effects of feeding stations were not considered. Kobler & Adamic, (2000) study on HS of bears in Slovenia resulted in showing the importance of forest patches in bear distribution. In Slovenian data in became clear that bears are less influenced by settlements inside prime habitats and forest patches are playing a more important role in bear distribution. Kusak & Huber, (1998) on other hand, identified food source as the main factor in bear distribution in Croatia. The HS study in Gorski Kotar region of Croatia, identified seasonal food, cover, roads and fragmentation to be the important variables in bear distribution (Kusak & Huber, 1998). However bears have shown strong variations in their habitat selection among individuals (Nielsen et al, 2002; Jansson, 2005;

Kaczensky et al, 2006; Mertzanis et al, 2008). Brown bears seem to have shifts in habitat selection among seasons for their diet (Munro et al, 2006) and to be less selective during mating season (Jansson, 2005) and males can travel great distances to reach areas with higher female density during that period (Krofel et al, 2010). In this study HS modelling was based on population level which averages the attributes of the population rather than individual preferences and varieties. This approach is more applicable in conservation and modelling of species distribution in larger scales. For other top predators in Europe like lynx, studies (Bunnefeld et al, 2006; Basille et al, 2009) suggest that selection of habitat is in correspondence to the abundance of food and the avoidance from humans which might induce mortalities as a consequence of the presence of food sources near to human landscapes. In the human-dense landscape of CaS, the distribution of Brown bears appear to be determined by the abundance of effortless food source at feeding stations inside forest patches with adequate area to support their ecological requirements, and more importantly the avoidance of risks associated with human presence, settlements, recreational hunting, and road collisions.

5.4. Recommendations for conservation

CaS are experiencing great changes in various domains in the recent years and most of these changes are expected to be negative for the bear existence (Huber et al, 2008a). Hence a clear vision on bear suitable habitats and its critical requirements is essential for conservation of this species. On the other hand, after centuries of persecutions of large carnivores in Europe, populations of most species are recovering (Kaczensky et al, 2004), although human-caused mortalities are still among the highest for them. The population in Slovenia is expanding at rate of 1.6-1.9 kilometers/year (Jerina & Adamic, 2008). As forest cover is increasing as well in Slovenia, further expansion of bears can be predicted and a previous study in Slovenia illustrated that there are still free niches available for bears to occupy (Jerina er al, 2003). However recent expansion in the distribution of the population toward the Alps has caused an increase in conflict between bears and livestock farmers (Jerina & Adamic, 2008). In this region, local communities seem to have lost their capacity in the acceptance of bears and public awareness and protective measures to alleviate bear damages must be implemented by wildlife managers. The process of natural recolonization of bears from CaS to Austria and Italy needs extensive efforts, this is in the implementation of HS studies such as this in identification of bear prime habitats and corridors.

Securing those areas in parallel to public awareness activities and clear conservation goals alongside participation of all stakeholders in such a process is inevitable. Using the HS model created in this study and data on barriers for bear movement like highways and cities, resistance values for bear movement can be derived and cost distance modelling can be performed to understand the critical habitats that can act as corridors for bear movements between subpopulations (Richard & Armstrong, 2010). Feeding stations can play an important role in shaping natural recolonization of bears toward the Alps if baseline requirements of such action are prepared.

The bear conservation issue in CaS is definitely a trans-boundary matter and must oversee bear exchanges within neighboring countries (Huber et al, 2008b). The connectivity of the Gorski Kotar population in Croatia with the Slovenian core area is one of the key points in the survival of bears in both countries. Bears in Slovenia have shown to be a sink population from dispersal from Croatia (Krofel et al, *submitted*) while exposed to different management policies, so it is recommended that as a pilot practice, transboundary areas adopt coordinated management policies in population census, hunting quotas and supplemental feeding and also cooperating in bear research. The Kocevje Regional Park in Slovenia has already joined the Risnjak National Park in Croatia which can facilitate international bear conservation efforts between these two countries. Also Triglav National Park – the only National Park in Slovenia – can play an important role in bear dispersal to Austria and Italy and securing a corridor for bears from the Dinaric Mountains to the Alps.

The impact of the presence of feeding stations on bear distribution in CaS is crucial and needs to be involved in other HS studies in the region and other parts of the world where this practice is taking place. The density of feeding stations, quantity and quality of food provided for bears, and periods which they feed animals should be investigated in the future for a better understanding of the influence of these stations on bears and their interactions among each other. Also the degree of habituation of bears to these areas should be investigated and in the case of positive results, limiting the application of this practice to certain locations and seasons needs to be agreed upon between conservationists and hunter communities. The application of supplemental feeding in the forests should consider the surrounding forest community and its growth stage to reduce damages to the trees (Sahlsten et al, 2010). Any damage to flora or inter-population conflicts resulting in marginalization of part of the the bear population (which can potentially create problem animals), should be considered when implementing this practice.

For further steps in understanding bear habitat in CaS, the effects of different forest types must be investigated. Also, from the results of this study, the location of critical forest patches, need to be identified and forestry activities must be limited in these areas so that there is the least disturbance to wildlife from these activities. The effects of highways on bear distribution have been well studied in the region (Kaczensky et al, 2003; Kusak et al, 2009). Closing unnecessary forest roads, avoiding logging in the denning seasons of bears and normalizing the re-forestation practices to natural patterns was suggested by Kusak & Huber, (1998) for the Gorski Kotar region in Croatia. More in depth studies on the effects of human settlements on bear ecology and seasonal movements due to mating or foraging must be undertaken. Also, wastes from human settlements are among important factors in CaS, which increases the chances of conflicts, and further study is needed. With great tourism potential and growth in the past few years in CaS, wildlife observation including bears, can be a source of income for hunting units, and its income can assist the conservation of bears indirectly. The visual appeal of GIS data from the GPS telemetry studies is among the most valuable role of this technique in conservation, which can be utilized in ecotourism as well.

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Appendices

Appendix1. CORINE land cover classes and modified categories in this study.

Grid codes classification in this study	Label	CORINE Landcover 2006 Grid code	CORINE Landcover 2006 Label
1	Artificial surfaces	1	Continuous urban fabric
1	Artificial surfaces	2	Discontinuous urban fabric
1	Artificial surfaces	3	Industrial or commercial units
1	Artificial surfaces	4	Road and rail networks and associated land
1	Artificial surfaces	5	Port areas
1	Artificial surfaces	6	Airports
1	Artificial surfaces	7	Mineral extraction sites
1	Artificial surfaces	8	Dump sites
1	Artificial surfaces	9	Construction sites
1	Artificial surfaces	10	Green urban areas
1	Artificial surfaces	11	Sport and leisure facilities
2	Agricultural areas	12	Non-irrigated arable land
2	Agricultural areas	13	Permanently irrigated land
2	Agricultural areas	14	Rice fields
2	Agricultural areas	15	Vineyards
2	Agricultural areas	16	Fruit trees and berry plantations
2	Agricultural areas	17	Olive groves
2	Agricultural areas	18	Pastures
2	Agricultural areas	19	Annual crops associated with permanent crops
2	Agricultural areas	20	Complex cultivation patterns
2	Agricultural areas	21	Land principally occupied by agriculture, with significant areas of natural vegetation
2	Agricultural areas	22	Agro-forestry areas
3	Forests	23	Broad-leaved forest
3	Forests	24	Coniferous forest
3	Forests	25	Mixed forest
4	Grasslands	26	Natural grasslands
4	Grasslands	27	Moors and heathland
4	Grasslands	28	Sclerophyllous vegetation
4	Grasslands	29	Transitional woodland-shrub

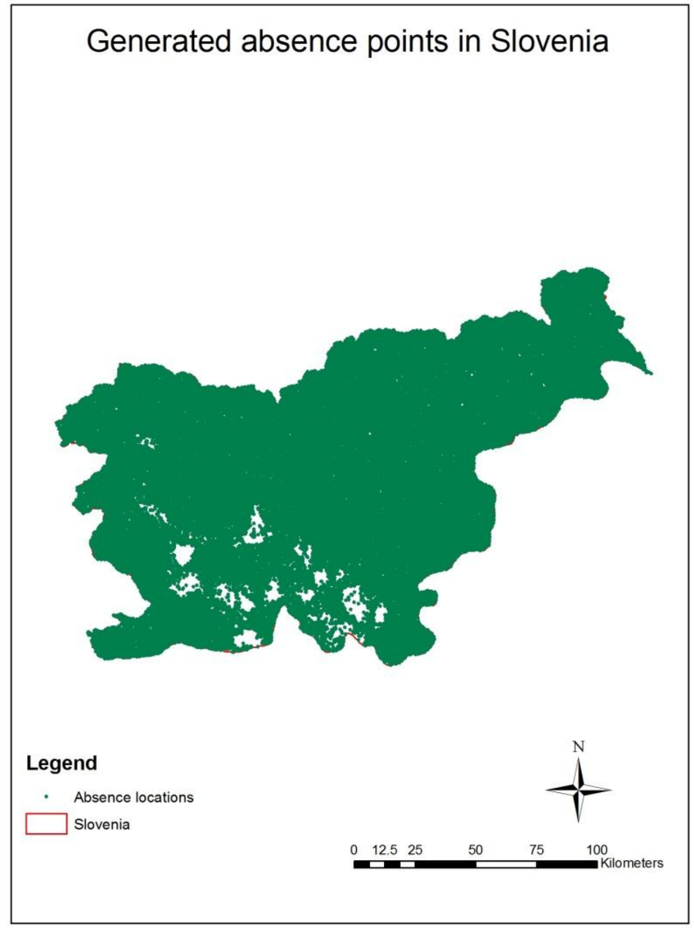
5	Open spaces with little or no vegetation	30	Beaches, dunes, sands
5	Open spaces with little or no vegetation	31	Bare rocks
5	Open spaces with little or no vegetation	32	Sparsely vegetated areas
5	Open spaces with little or no vegetation	33	Burnt areas
5	Open spaces with little or no vegetation	34	Glaciers and perpetual snow
6	Wetlands and water bodies	35	Inland marshes
6	Wetlands and water bodies	36	Peat bogs
6	Wetlands and water bodies	37	Salt marshes
6	Wetlands and water bodies	38	Salines
6	Wetlands and water bodies	39	Intertidal flats
6	Wetlands and water bodies	40	Water courses
6	Wetlands and water bodies	41	Water bodies
6	Wetlands and water bodies	42	Coastal lagoons
6	Wetlands and water bodies	43	Estuaries
6	Wetlands and water bodies	44	Sea and ocean
7	NoData	45	NODATA
7	NoData	46	UNCLASSIFIED LAND SURFACE
7	NoData	47	UNCLASSIFIED WATER BODIES

Appendix 2. Information on GPS collared bears in Croatia

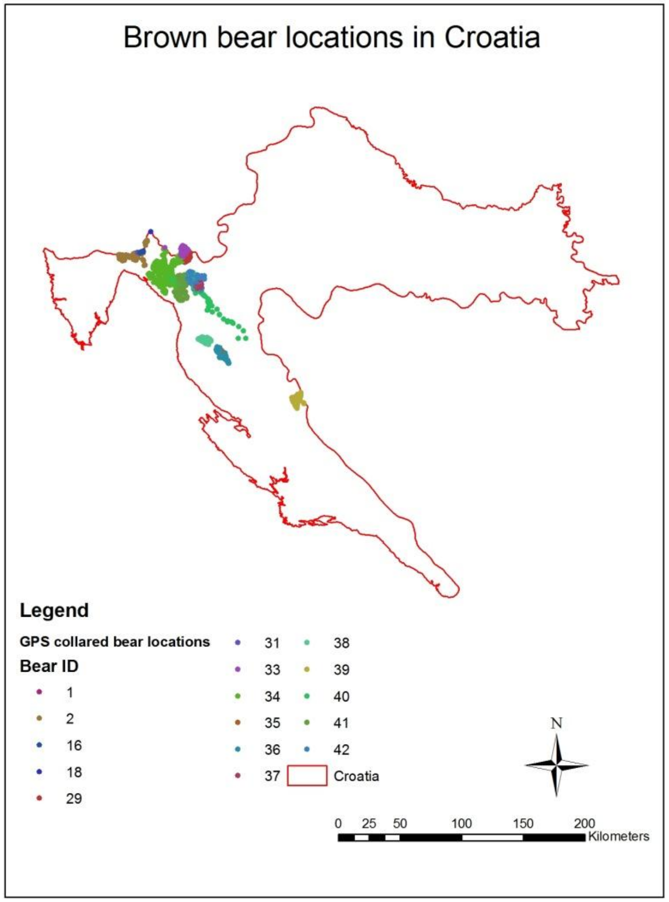
ID	Bear name	Age	Sex	Start date	End date	Total days of monitoring	Number of GPS locations
34	Marko12	5.5	M	10/09/2004	24/10/2005	409	2762
35	Srecko15	?	M	23/04/2005	24/04/2005	1	8
36	Ela16	2.3	F	07/05/2005	27/07/2005	81	582
37	Gama17	4.5	F	21/05/2005	28/11/2005	191	922
38	Iva18	2.5	F	22/05/2005	03/07/2005	42	319
39	Una21	2.5	F	23/09/2005	18/07/2006	398	997
40	Mladen8	4.5	M	25/09/2003	06/05/2004	224	880
41	Mijo46	4	M	15/09/2008	17/05/2009	244	979
42	Slaven47	2.7	M	18/09/2008	24/09/2009	371	1745
43	Zlatko53	12	M	19/10/2009	26/12/2009	68	696

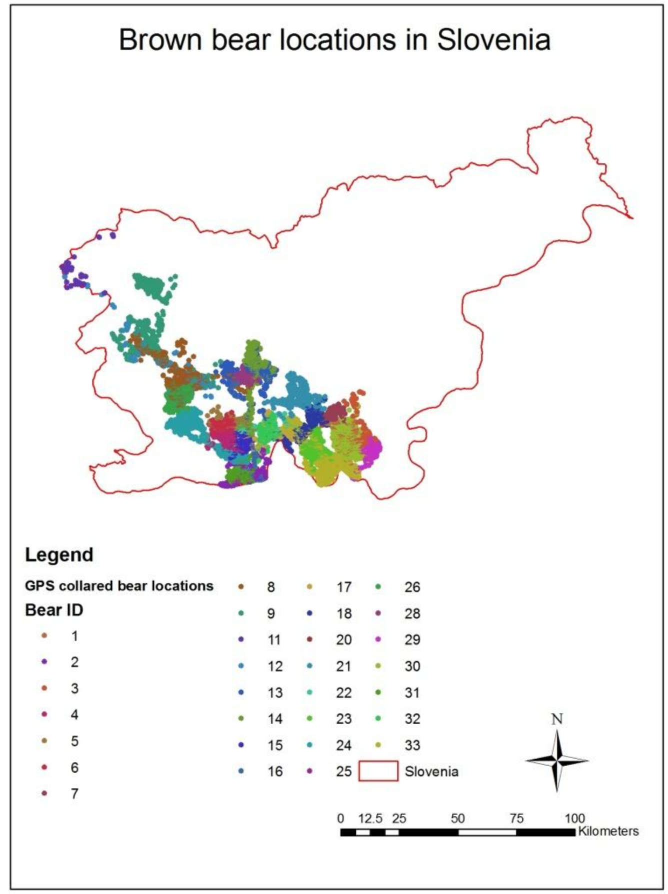
Appendix 3. Information GPS collared bears in Slovenia (*: translcoated individuals).

ID	Bear name	Sex	Age	Start date	End date	Total days of monitoring	Number of GPS locations
1	ALJOŠA	M	+4	30.4.2006	8.10.2006	161	1947
2	VALENTIN	M	+3	24.3.2005	11.4.2006	383	4598
3	PETER	M	4-6	25.4.2005	23.11.2005	212	2552
4	ANA S	F	+6	2.4.2005	9.9.2006	525	5565
5	ZORAN	M	3-4	23.3.2005	1.5.2005	39	649
6	MARJETA	F	9-10	12.5.2005	18.5.2006	371	5397
7	ANKA	F	4-5	4.8.2005	31.5.2006	300	3557
8	BORUT	M	12	19.5.2007	11.5.2008	358	4990
9	BRANKO	M	12-13	8.5.2007	25.12.2007	231	5171
10	BOHINJC*	M	+4	12.2.2008	9.3.2008	26	638
11	ANDREA	M	8-9	3.4.2007	29.8.2007	148	No data
12	BEPI	M	+4	5.3.2007	27.9.2007	206	No data
13	ALOJZIJ	M	3+	4.4.2009	1.10.2009	180	4309
14	ANA R	F	5+	1.11.2008	21.10.2009	354	6164
15	PEPCA	F	+8	18.10.2008	31.10.2009	378	6212
16	IGOR	M	+3	5.11.2008	12.4.2009	158	1924
17	HRIBAR	M	+7	24.10.2008	19.11.2008	26	436
18	ZORA	F	+3	16.11.2008	29.10.2009	347	6190
19	ROŽNIK*	M	+3	17.4.2009	30.5.2009	43	1215
20	ŽIVA	F	+4	20.10.2008	12.1.2009	84	907
21	NEJC	M	+5	3.5.2009	5.10.2009	155	3721
22	KAREL	M	+3	27.3.2009	16.4.2009	20	482
23	JANI	M	+4	17.4.2009	10.6.2009	54	1170
24	SENOŽEČANKA	F	+5	4.5.2009	3.5.2010	364	8737
25	FRANCE	M	+9	15.10.2009	6.12.2009	52	1245
26	GORANKA	F	+15	30.1.2009	4.5.2010	459	6898
27	NEŽA*	F	+1	24.11.2008	19.12.2008	25	343
28	EVA	F	+4	14.11.2008	30.4.2010	532	6924
29	KATJA	F	+3	15.11.2008	17.8.2009	275	4300
30	HOBI	M	+20	20.10.2008	4.1.2010	441	6565
31	MIRKA	F	+2	20.10.2008	18.4.2010	545	7226
32	BORA	F	+3	31.3.2009	14.11.2009	228	4836
33	PEČKO	M	+15	19.10.2008	18.2.2010	487	6756

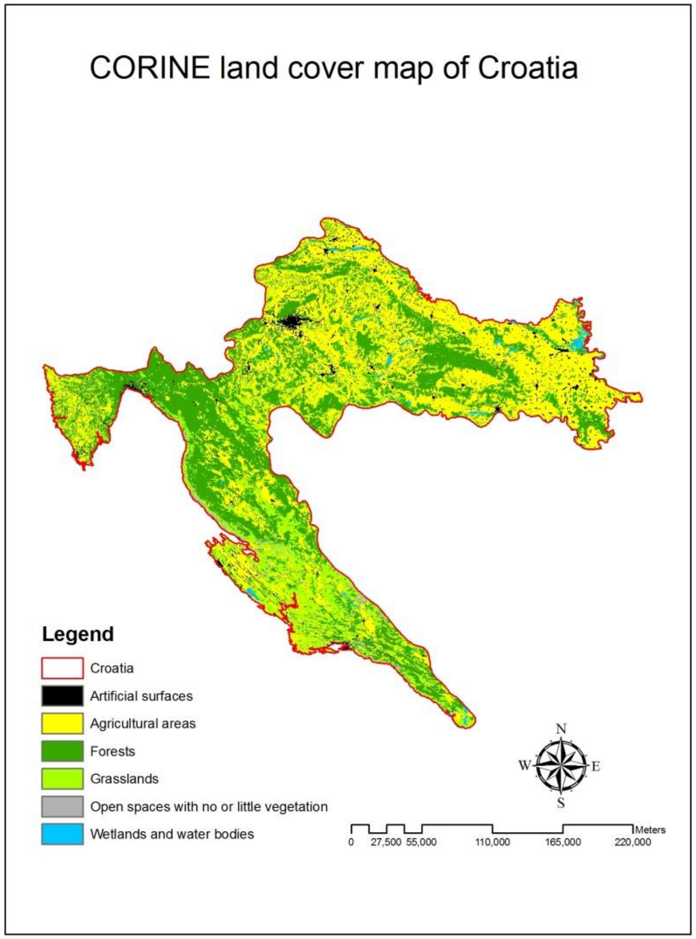


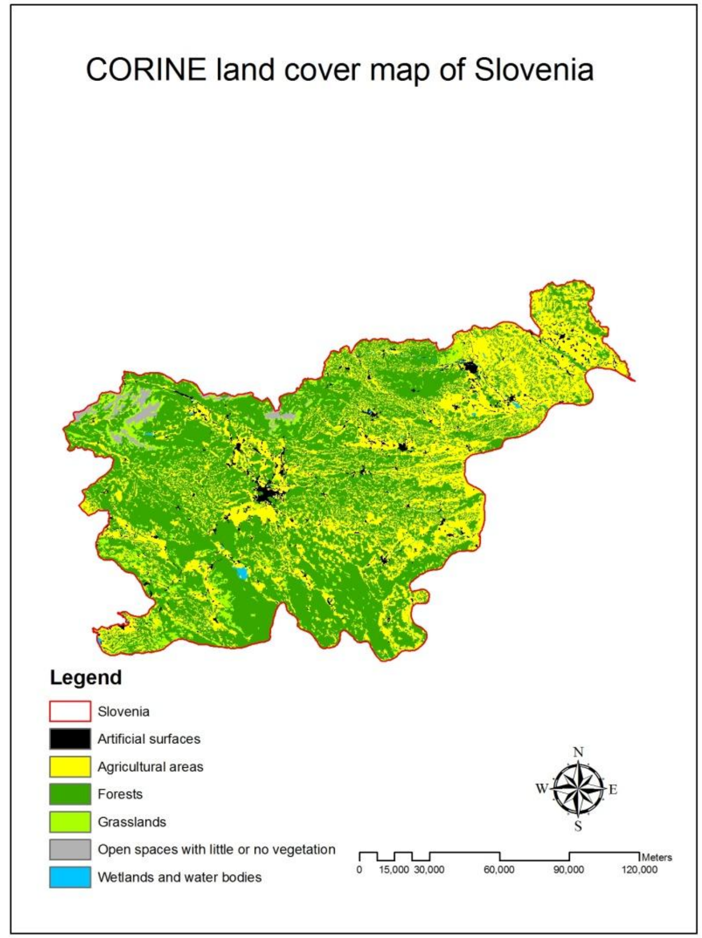
Appendix 4. Generated pseudo-absences in Croatia and Slovenia.



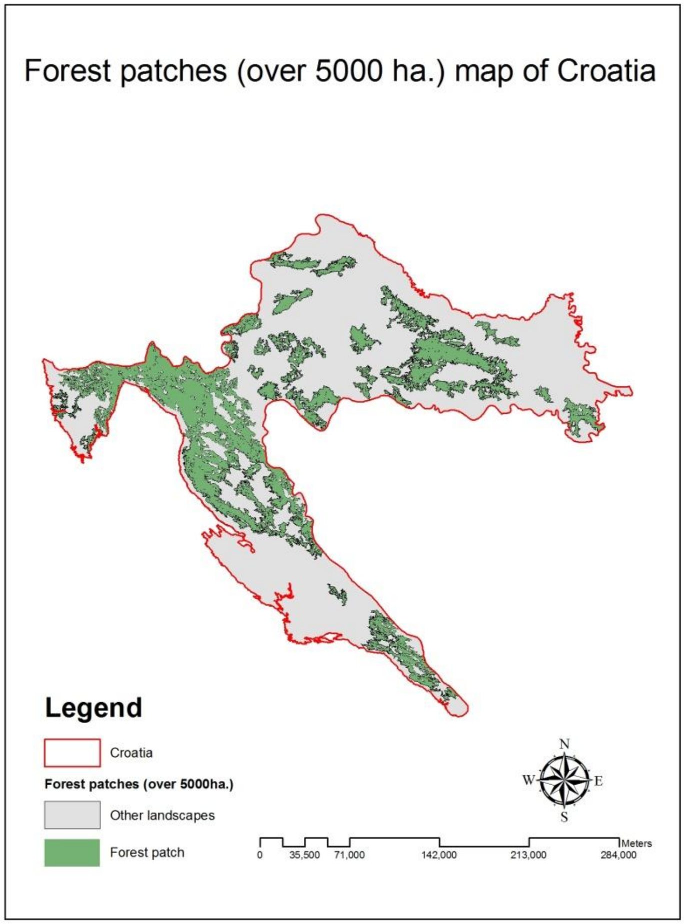


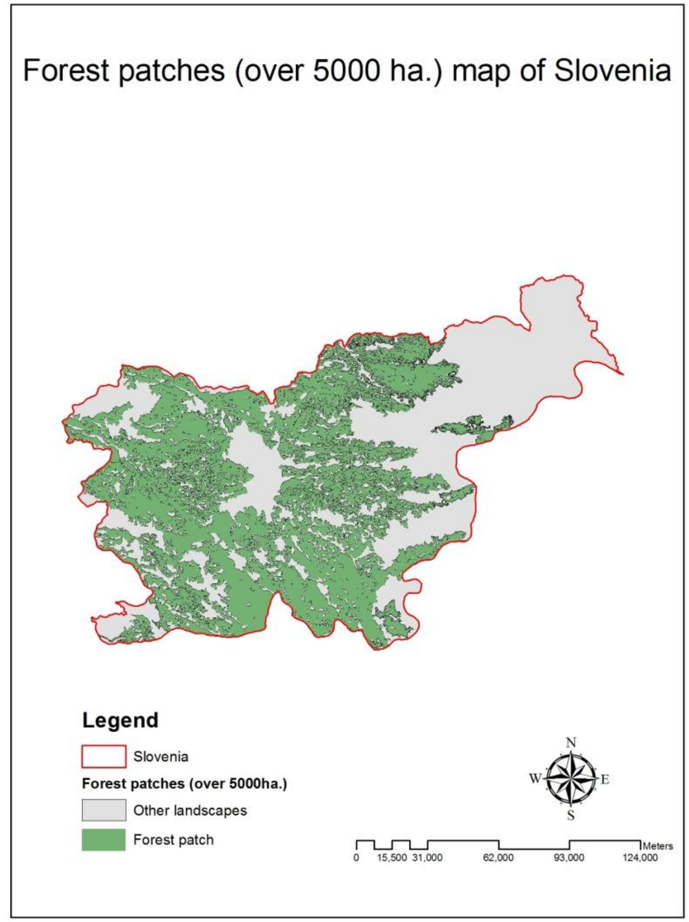
Appendix 5. Brown bear locations from GPS collaring in Croatia and Slovenia



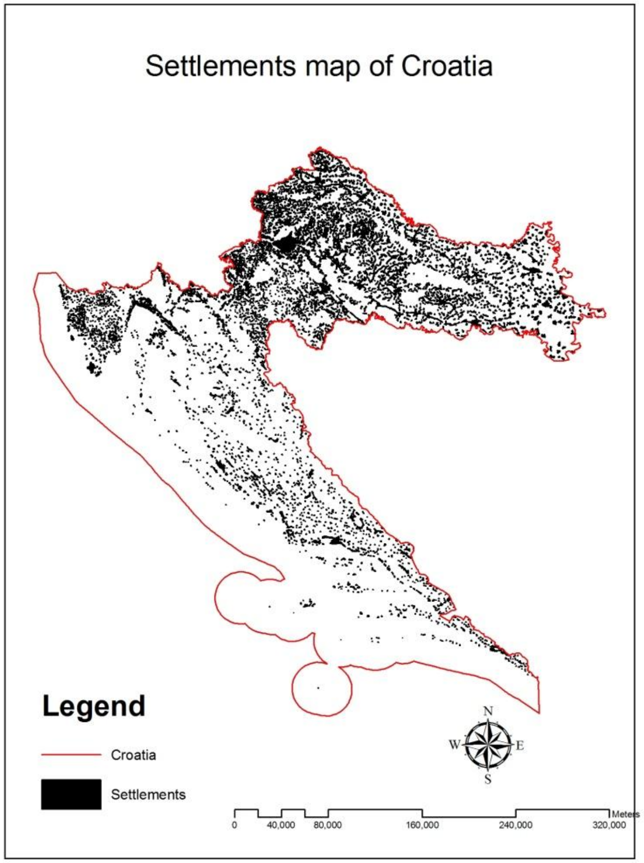


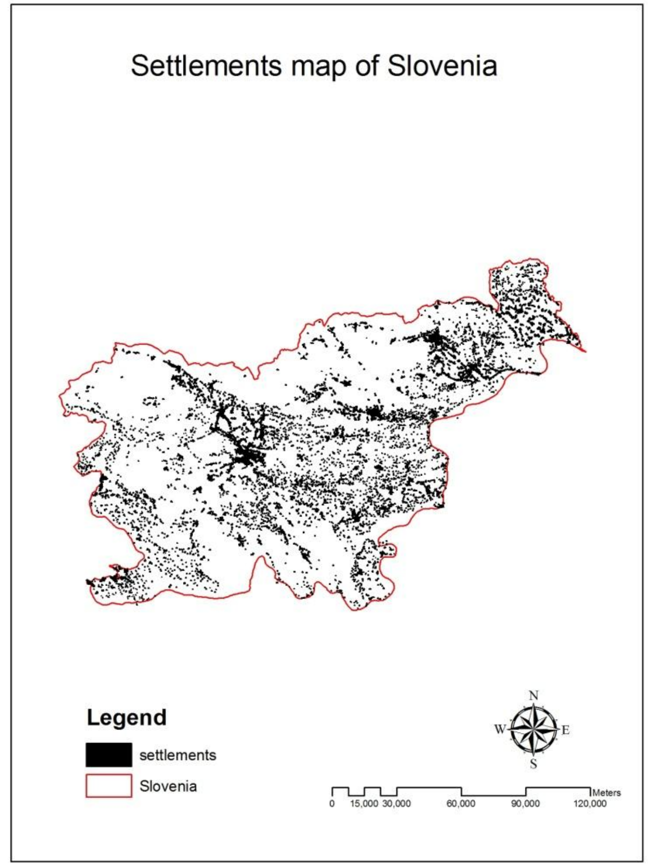
Appendix 6. CORINE land cover image of Croatia and Slovenia



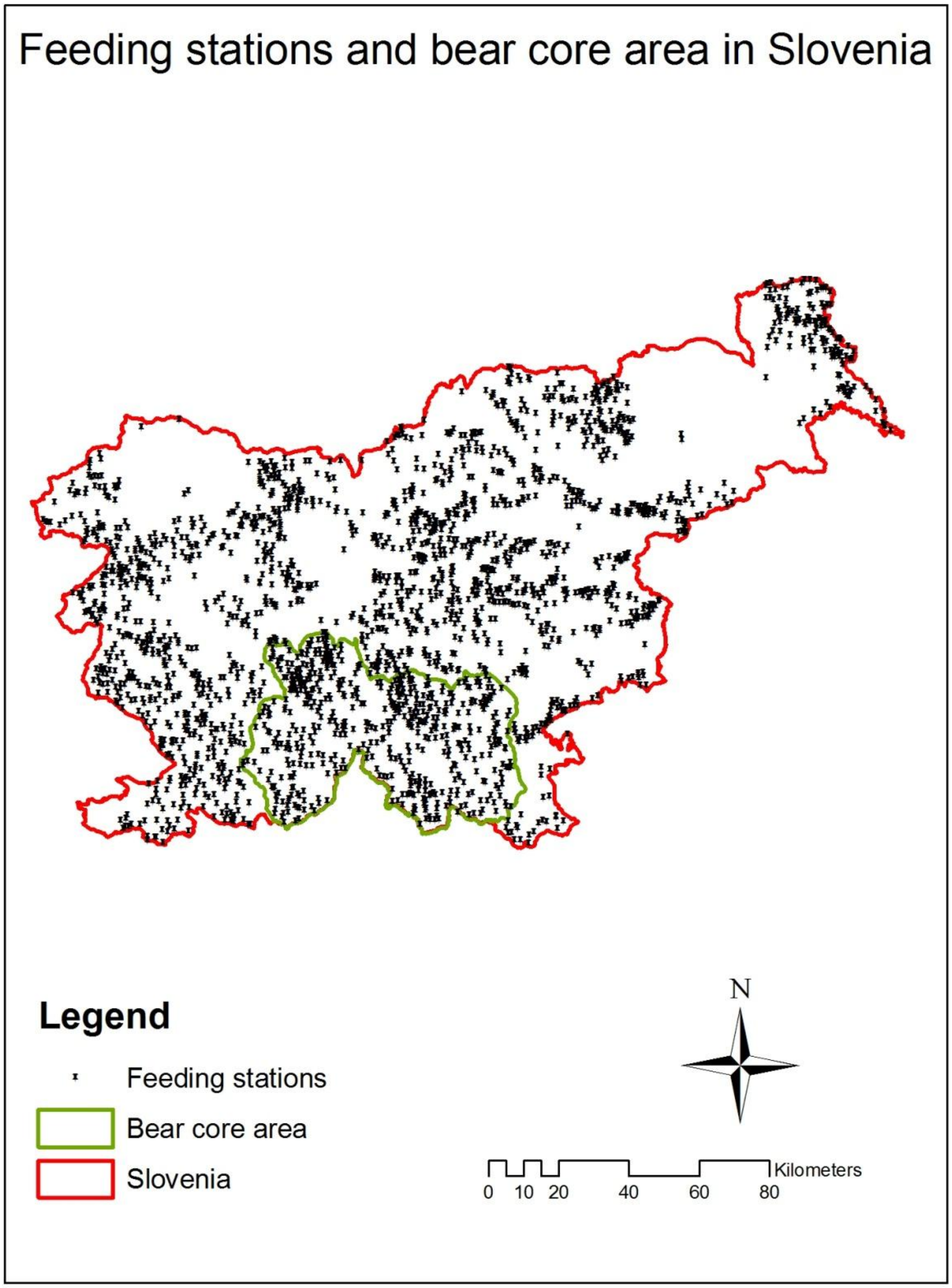


Appendix 7. Forest patches over 5000 hectares in Croatia and Slovenia





Appendix 8. Distribution of settlements in Croatia and Slovenia



Appendix 9. Location of feeding stations in Slovenia.