BROWN BEARS IN SLOVENIA: IDENTIFYING LOCATIONS FOR CONSTRUCTION OF WILDLIFE BRIDGES ACROSS HIGHWAYS

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Abstract

Slovenia lies on the north-westernmost edge of continuous Dinaric-Eastern Alps population of the Eurasian brown bear (*Ursus arctos*). It has a stable population of 320-400 bears, occupying a range of about 5000 km^2, predominantly in the most forested southern regions along the state border to Croatia. The alpine and pre-alpine regions of western Slovenia represent an essential link for the expansion of brown bears from Dinaric mountains into the Alps. With recent construction of the highway network in these regions, new barriers through the potential bear corridors have been introduced threatening connectivity of large patches of core habitat. The paper deals with the results of the GIS and artificial intelligence based modeling, aimed to identify the most suitable locations for the construction of wildlife bridges / underpasses, enabling safer crossing of the highway by the bears. An expert system for classifying the habitat suitability for brown bear was developed. The knowledge base for the expert system, induced by a machine learning method from recorded bear sightings, was linked to the GIS thematic layers. The main factors considered by the expert system were: the land use types (rendered by the CORINE Land Cover database), other human impacts and the topography. The expert system was implemented in GIS, thus enabling the mapping of suitable brown bear habitats. Broad potential dispersal corridors were identified, taking into account actual land cover between the patches of suitable habitat. Thus identified most probable locations of highway crossings by the brown bears were taken as the most convenient locations for the construction of the wildlife bridges / underpasses.

Introduction

Slovenia lies on the north-westernmost edge of the Dinaric-Eastern Alps population of the brown bear, extending over large forested areas beginning in the Eastern Alps of Austria and northeastern Italy, and downwards to the Pindus mountain range in Greece. The entire population size is estimated to about 2.800 bears (Swenson et al. 1997). Large forested areas of south-central Slovenia represent the core habitat of brown bear in Slovenia, but also that of wolf and lynx. The area is connected with that of Gorski Kotar plateau in Croatia in an unified block of habitats. Calculated size of the brown bear population in Slovenia, derived from the results of autumn census in the period 1993-1997, is between 320 - 400 animals. Considering the structure of brown bears sighted on the feeding places during the autumn census, the population seems to be highly reproductive (Adamic, Koren 1998). The Dinaric beech-fir forests of south-central Slovenia represent the core habitat type of the brown bear, but the species range is in a progressive expansion, extending towards the west, into the Littoral Karst and towards north-west into the Alps (Adamic 1994, 1997a). Increasing frequencies of reliable signs of bear occurrence (sightings, tracks, prey rests, etc.) in the period 1972 - 1997 in the areas of penetration, were met by fear and aversion of local inhabitants, yet unaccustomed to a yearlong presence of bears. Increased predation on sheep in poorly protected alpine pastures was also among the consequences of the expansion. In 1993 the Government of Slovenia adopted the Protection of Endangered Species Act, by which the brown bear was declared a yearlong protected species even in the Alps, despite the protests of local communities.

With its geographical position and a viable bear population, the role of Slovenia in future welfare of the species in central Europe is undoubtedly very important. Future conservation strategy in Slovenia is aimed towards a long term preservation of viable population of brown bear with surplus reproduction rates. This will ensure the persistence of the population under increased pressures, which are to be expected in future even in the key habitats. Surplus animals might be moderately harvested and live-captured for planned restocking in the Alps and other parts of historical species range, and accelerated emigrations towards the Alps will also be enabled. Spatial extension of current core bear conservation area of about 3.500 km^2, into the north-western part of the Dinaric mountain range and into the Littoral Karst, is of a crucial importance for the conservation of the species in Slovenia. Additional 1.800 km^2 of bear habitat might be thus provided.

According to the study of Corsi et al. (1998) the Alps represent a vast area of potential, yet unoccupied brown bear habitat of different degrees of suitability. Although it was believed that the brown bear disappeared in the Eastern Alps, too (Roth 1987), more detailed studies and new data collection on the occurrence of the bears in southeastern Alps has led to the conclusion that it is more the question of definition whether the brown bear was ever extirpated in the region or not. It is admissible to say that the bears never disappeared from the south-eastern Alps, but continued to survive there (Gutleb et al. 1997). Therefore, the question whether there are suitable species habitats still available in the Alps seems superfluous, and the right of the brown bear to return in the historic habitats in the Alps should be respected.

Emigrant bears leaving the source habitats in the south-central Slovenia, dispersing north-westward and penetrating into the Nanos mountains, have to cross the fenced highway section between Vrhnika and Razdrto (Fig. 2). From there they proceed towards the Julian Alps and the surrounding mountains. Some of them continue to move north across the state border into the adjacent areas of Italy and Austria. The northwestern corridor seems to be the main way of spreading into the Eastern Alps. Since 5 cases of bear-vehicle collisions on the 30 km highway stretch Vrhnika-Razdrto took place in the same year (1992), the Ministry of Environment recommended a study to estimate the impacts of the existing and planned highway sections on the bear habitat and migration corridors. In 1995 the Parliament decided that special bear-bridge(s) will have to be built on the highway section, where the majority of bear-vehicle collisions took place (Jonozovic et al. 1997).

In source habitats the reproduction rate of the population exceeds the mortality rate. The surplus individuals in saturated populations move out of parental habitats. Due to it's mobility the brown bear has high selective ability, therefore the emigrant individuals usually seek suitable yet unoccupied or sparsely settled, even distant patches of suitable habitat types. Not rarely the surplus individuals emigrate into less productive sink habitats where within-habitat reproduction is insufficient to cope with within-habitat mortality (Pulliam, Danielson 1991, Swenson et al. 1998). The appearance of bear-unfriendly human activity (e.g.livestock husbandry, military exercises, etc.) in highly productive source habitats may seriously affect their function and even degrade them into habitat sinks. Vast Dinaric beech-fir forests of south-central Slovenia have the function of highly productive source habitats. Thus, the rest of Slovenia, with the exception of northwestern part of the Dinaric mountain range and the patches of suitable habitat in Pre-alps and Alps, can be qualified as the habitat sink. Human generated mortality is among strong evidences of habitat status. The sources of mortality of brown bears in Slovenia are typically human-generated. Of 257 extracted bears in the period 1991-1997, 96% were killed by the hunters and in traffic collisions (Adamic 1997b). Being aware of potential bear conservation problems due to the construction of the new highways, our research since 1992 was mostly focused at the mentioned problems. In 1993 also a joint telemetric project on brown bear behavior along the highway section Vrhnika-Razdrto, with the participation of the University of Ljubljana (the Department of Forestry and Renewable Forest Resources), University of Vienna (Institut für Wildbiologie und Jagdwirtschaft), the Munich Wildlife Society and the Hunters Association of Slovenia was launched

(Kaczensky et al. 1995, Kaczensky et al. 1996). In 1997 we started a 3 year study of optimal locations of bear-bridges and other mitigation measures, ensuring safer crossing of the highways by the brown bears and other large mammals. The study was supported by the State Road Company. From our previous studies on the behaviour of the bears along the fenced highway Ljubljana-Razdrto (Kaczensky et al. 1996) we realized that the bears skillfully climb the highway fence, but few of them manage to escape the vehicles on the highway lane and thus suffer in the traffic collisions. Learning to use safer ways of crossing highway barriers on their traditional pathways usually takes time. The first step of our mitigation strategy was to block free crossing of the highway fence by the brown bears, with additional high-power electric protection on a 5 km stretch in section 1 (table 1). Tracking with sand beds in the underpasses and with the automatic (Trailmaster) cameras mounted on highway bridges helped us to study the use of (non wildlife-friendly) facilities by the wildlife during the attempts to cross the highways.

Study Area

Slovenia is one of the smaller European countries, located between the Alps, the Mediterranean coast and the Pannonian flatlands (fig. 1). According to the last survey, forests cover 57% of the national territory, which makes Slovenia the most forested European country after the Scandinavian countries. Slovenia is small in terms of area (20.000 km^2) and population (2 million), however it is noted by an outstanding geographical and ecological variability with three distinct climates – alpine, submediterranean and continental. In the colder and humid alpine and karstic regions in the west and in the south, forests with high timber volume abound, dominated by spruce (*Picea abies*), beech (*Fagus sylvatica*) and fir (*Abies alba*). The subpannonic region in the east is where most of the agriculture is centered, while the submediterranean region in the coastal hinterland has been marked by a pronounced spontaneous reforestation of the abandoned farmland by pine (*Pinus nigra*), oak (*Quercus pubescens*) and hop hornbeam (*Ostrya carpinifolia*).

The oldest section of the fenced 6-lane highway, built in 1972, between the capital of Ljubljana and the Adriatic coast, is already cutting through the prime bear habitat. In 1992 Slovenia embarked on a plan to modernize and to expand its highway network, which is going to affect the bear habitat even more. The study area covers 6.993 km^2 of the most forested regions in the south-western part of the country, the littoral region, western parts of the core protected area and most of the area along the border to Italy (Fig. 2).

This study is focused at the oldest highway section south of the capital with the recently built extension towards the coast and at a side-leg towards the border city of Nova Gorica, which is under construction. When considering the possible wildlife bridge / underpass sites, we were specifically interested in 3 highway sections (Tab. 1, Fig. 2), where most bear-vehicle collisions took place and where there are several registered bear crossing spots, including climbing over the fence. 13 bridges and 7 underpasses traverse the studied highway sections, and there are also 3 highway viaducts across valleys. Although not wildlife-friendly, several of those object have been also traveled by bears as proven by sightings, tracks in sand-beds and photographs taken by Trailmaster monitor cameras.

Methods

Knowing the present and the potential species distribution as well as the corridors of movement is essential for sensible placement of wildlife bridges / underpasses across highways. In the paper we assess the potential sites for wildlife bridges / underpasses within the study area, using existing geo-coded data on bear population spatial distribution as well as GIS data layers covering several ecological aspects of the study area. We developed first a habitat suitability model using artificial intelligence (AI) tools and a raster geographic information system (GIS), assuming that the available recorded observations of brown bear approximate the actual spatial preferences of the bear population reasonably well, so they present a suitable basis for automated creation of the knowledge base for subsequent classification of habitat suitability within the study area. Then, using GIS-based least cost route analysis, we identified the broad potential corridors for the dispersal of the brown bears from the core protected area across the highway and towards the Alps. Other workers have already shown that the least cost route analysis can help in identifying the priority areas for wildlife management to improve the connectivity between the core protected ecosystems (Walker and Craighead). Locations of the most probable highway crossings, identified in this way, were taken as the most convenient locations for the construction of the wildlife bridges / underpasses.

Habitat models are receiving attention as tools to understand habitat relations of the organisms, to evaluate habitat quality and to develop habitat management strategies (Verner, Morrison, Ralph 1986). Such models can be either (1) developed *a priori* based on expert knowledge and by successive approximation and testing on new data or (2) they can be induced *a posteriori* from the already collected data. In the first case often the method of acquiring knowledge in a computer usable format involves a domain expert, who expresses his or her knowledge, and a knowledge engineer, who encodes this knowledge into computer usable knowledge base. This presents the problem of "knowledge acquisition bottleneck", because (1) domain experts are often incapable of formulating their knowledge explicitly, systematically and completely enough to form a computer application and (2) the process is time-consuming (Bratko et al. 1989). The second approach with the *a posteriori* induction of knowledge base was used for this study, because in Slovenia a lot of field data and geolocated observations of brown bears have been systematically collected through the years by members of hunting clubs or Forestry Service for bear population monitoring. The geolocated sightings of the animals also inherently contain some information on bears' preferences regarding the properties of their habitat. According to Corsi et al. (1998), given an adequate number of locations the "ecological signature" may be derived and used to measure the ecological distance of any given location in the study area from the "optimal" conditions. Conventional inductive statistics, multivariate techniques and logistic regression (Pereira and Itami 1991, Mladenoff 1995) are often used to develop habitat suitability models from such data. In addition to statistical methods, which give more or less "black-box" models, there are also AI methods, which can automate knowledge base building and some of them can present the learned knowledge in an easy to understand form (Moore et al. 1991, Fabricius and Coetzee 1992). Machine learning approaches, as a field within AI, include statistical techniques like Bayesian classification, neural networks, nearest neighbour methods and symbolic techniques like classification / regression trees, equation discovery and inductive logic programming (Kubat et al. 1997). In our case we employed the See5 version 1.10 software (Rulequest Research 1999), which uses an inductive learning algorithm to generate classifiers in the form of decision trees, from training dataset. The training dataset consisted of examples (pixels in our case). Each example belonged to one class and was specified with the attribute values (i.e. linked to other GIS layers), which can be either continuous or discrete. The induced decision tree formed the knowledge base, which was part of an expert system for classifying the habitat suitability. The knowledge base was linked to the raster GIS thematic layers, enabling us to determine potential habitat suitability of the entire study area.

The training dataset was based on the bear sightings gathered between 1990 and 1998 (Adamic 1999) and on results of a previous project, concerned with radio-tracking of bears between 1993 and 1995 (Kaczensky et al. 1996, Kobler et al. 1997). Only locations of females (sightings with cubs) were taken into consideration, because we were interested in the "optimal" potential habitat, best presented by females with cubs. Males migrate across a broader area and therefore tend to be less selective regarding their habitat. Together we used 1.517 female locations, assuming that the recorded locations represent the actual spatial preferences of the bear population in the study area reasonably well. Due to imprecise locations of sightings and to random excursions of bears outside their home-range, we also expected some noise in the data. Noisy data could lead to several problems when inducing a decision tree: incompleteness of the training dataset, low classification accuracy on new data, the induced tree could trace noise (over-fitting) and it could be too large (poor comprehensibility)

Figure 1: Present distribution of the brown bear in Europe (source: WWF 1999. Europe's Carnivores: A Conservation Challenge for the 21st Century. A WWF - UK Report - February 1999), location of the study area and the analyzed highway.

Table 1: The highway sections of interest.

Highway section*	1. Vrhnika – Laze	2. Unec - Postojna	3. Razdrto - Dolenja vas
Length	20 km	10 km	6 km
In operation since	1972	1972	1995
Bear – vehicle collisions**	6	3	1
Bridges	8	2 road + 1 railway	2
B. used by bears	4	1 + 1	1
Underpasses	5	2	0
U. used by bears	2	0	0
Highway viaducts (lenght)	0	1 (593 m)	2 (160 m and 265 m)
V. crossed beneath by bears	0	1	2

*For the location of the analyzed highway sections also refer to Fig. 2.
**The record of bear - vehicle collisions has been systematically kept since 1990.

Table 2: Distribution of the training sample.

Land cover type	Habitat	Non-habitat
1. Forest, shrub	741 pixels	219 pixels
2. Grassland, naturally nonvegetated, wetland, water	75 pixels	213 pixels
3. Agriculture	14 pixels	201 pixels
4. Settlements, other artificial	0 pixels	192 pixels
All	**830 pixels**	**825 pixels**

Table 3: Resistance to movement through a cell.

Land cover type	Relative resistance to movement
1. Bear habitat	1
2. Other forest, shrub	10
3. Grassland, naturally nonvegetated, wetland, water	100
4. Agriculture	1.000
5. Settlements, other artificial	10.000

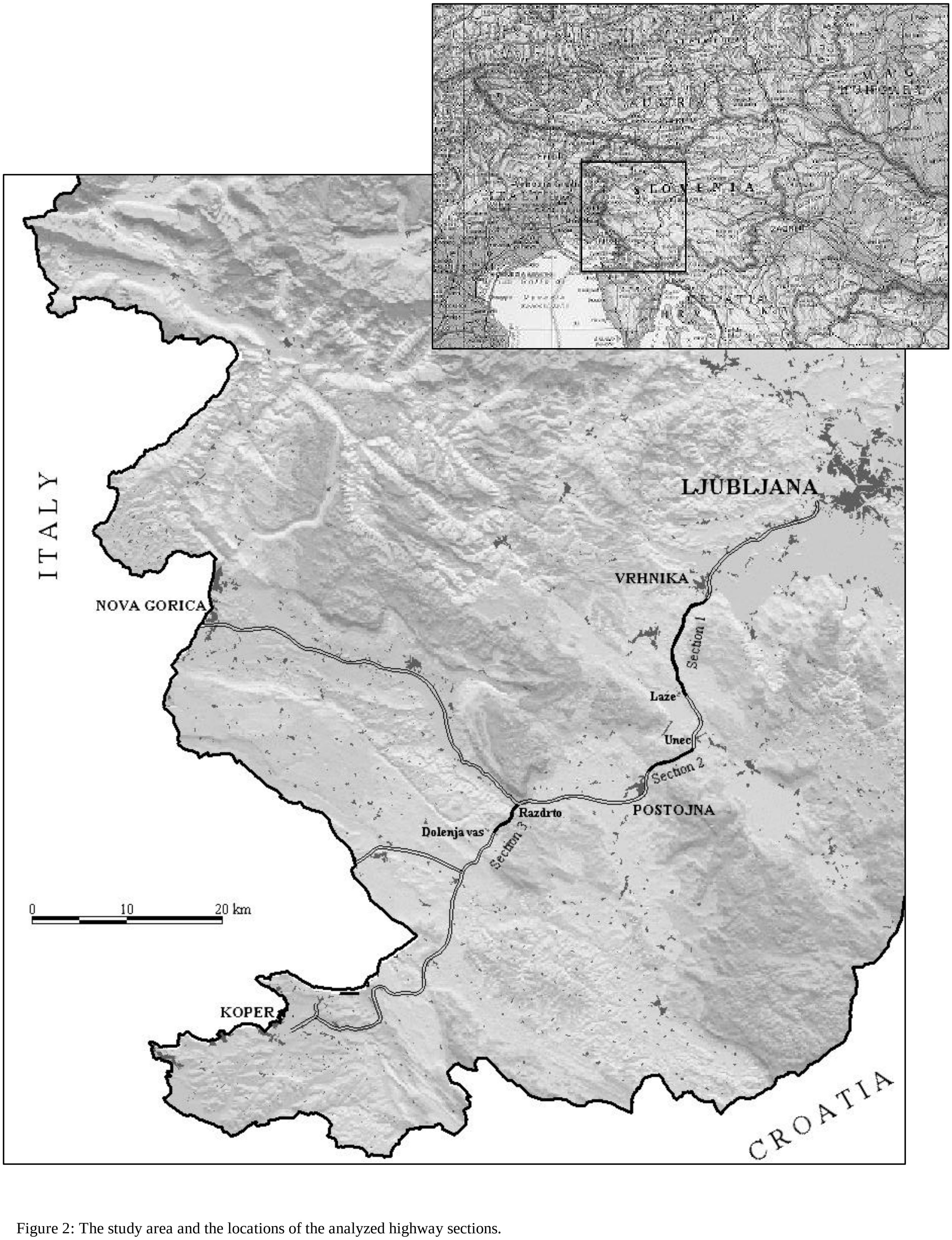
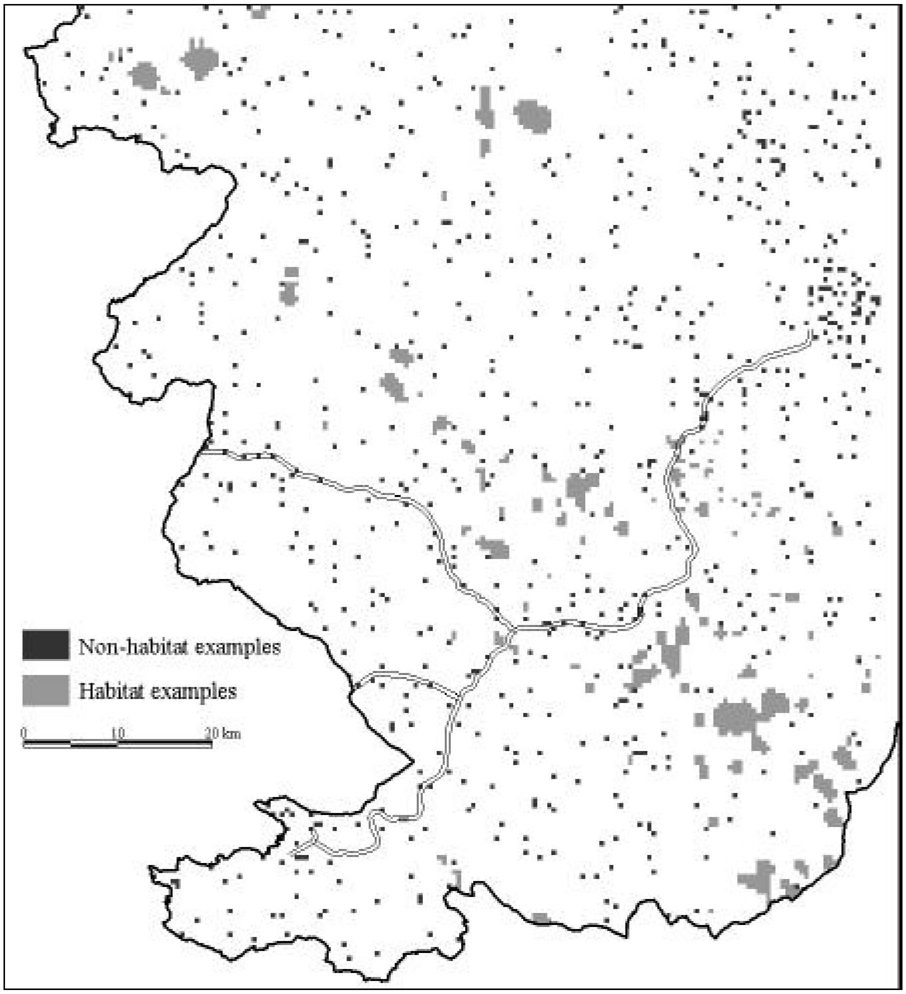
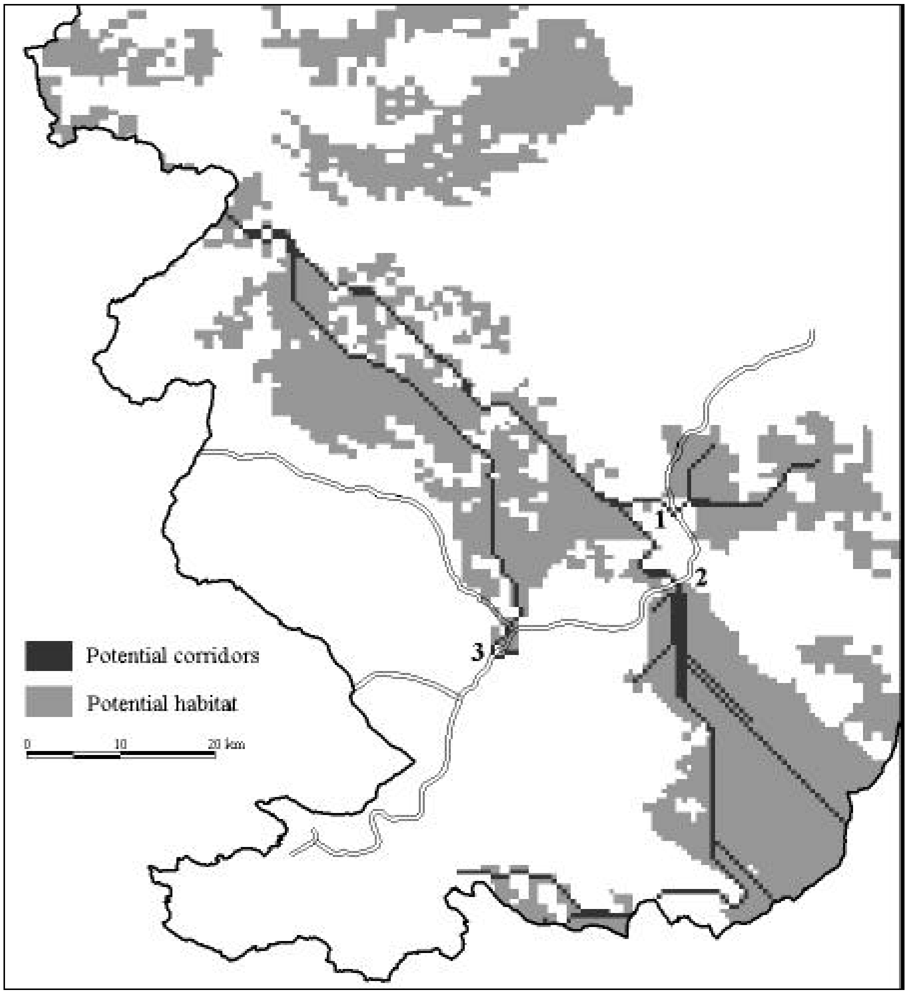


Figure 2: The study area and the locations of the analyzed highway sections.



Non-habitat examples
Habitat examples
0
10
20 km



(a) (b)

Figure 3: The training sample (a) and the final (filtered) habitat map with potential movement routes (b) and the expected locations of the wildlife bridges / underpasses.

(Bratko). To minimize the effect of noise on machine learning results we decided (1) instead of using the "raw" locations, to use an estimate of the home-range (HR) area and (2) for the model to have a coarse (i.e. 500 m) spatial resolution. The kernel method as implemented in KERNELHR software (Seamann, Griffith and Powell 1998) was used to determine the HR area based on available locations. The HR thus encompassed 830 pixels as the positive training examples. We also randomly sampled a similar number of negative examples within the rest of the study area, which presumably is less (or not at all) suitable for bear habitat. To account for every possible land cover type, the negative examples were sampled in a stratified random manner with approximately similar number of examples per land cover type (Fig. 3a, Tab. 2).

Via a raster GIS the training pixels were then linked to the ancillary GIS information layers explaining the distribution of the HR. These layers included:

1. CORINE Land Cover database (Kobler et al. 1998, European Commission 1993). This database shows 44 types of land cover features, identified from Landsat TM imagery and ancillary aerial photographs. For the purpose of this study the 44 categories were aggregated into 4 general land cover types (listed in Tab. 2), most relevant to habitat suitability. Several other attributes were derived from this database, including forest patch size, distance to forest edge and proportion of each of the four main land cover types in the cells of a 1 by 1 km grid. In this way we accounted for the animals' awareness of the surroundings.
2. Digital terrain model at a 100x100 m resolution by the Geodetic Service of Slovenia, from which various derivatives were computed.
3. Several attributes of the forest inventory database (by the Forest Service of Slovenia) at the level of forest compartment (average area 20 ha), including timber volume, dominant tree species, dominant vegetation association, canopy cover and stand age class.
4. Map of settlements, digitized off a 1:50.000 map (by the Geodetic Service of Slovenia), from which distance to nearest settlement was computed. To account for the effects of residents' number only the settlements exceeding the threshold of 5 ha were taken into consideration.
5. Some human demographics at the level of geographical sub-regions (average area 400 km^2) including density of population, average age and percentage of rural population.

Although most of the above mentioned layers have a spatial resolution better than 500 m, we decided for a 500 m resolution of the model, because bears regularly move over large distances and a finely grained model may be unrealistically sensitive to local variation. The chosen resolution also offered a reasonable level of detail for estimation of suitable location for the wildlife bridges / underpasses.

When inducing decision tree with the See5 we tried to optimize the model by attribute selection and by adjusting the See5 learning parameters. The following criteria were considered:

1. Accuracy of the habitat / non-habitat classification, as estimated by a 10-fold cross-validation (the examples in the data file are divided into 10 blocks of roughly the same size and class distribution. For each block in turn, a classifier is constructed from the examples in the remaining blocks and tested on the examples in the hold-out block. In this way, each example is used just once as a test example. The error rate of a classifier produced from all the examples is estimated as the ratio of the total number of errors on the hold-out examples to the total number of examples).
2. Checking the decision tree for unreasonable deviation from the established domain knowledge. Such deviations could be due to either noisy / incomplete learning dataset or errors in ancillary GIS data layers.
3. Checking the decision tree for over-fitting the training dataset (i.e. fitting the noise).
4. Checking for obvious spatial inconsistencies of the GIS-visualized model, which was done by a domain expert, familiar with the bear ecology in the study area.

The optimal decision tree induced by See5 did not include any consideration of habitat patch size, therefore a spatial filter with a 5.000 ha threshold was applied on the resulting habitat map to exclude small isolated fragments.

Next we delineated the most likely bear corridors at a regional scale from the broader core habitat area towards the Alps and the Alpine part of the Italian border in the general direction of dispersion from the population source area. Using the previously developed habitat map, the above mentioned land cover map, a highway map and the IDRISI GIS software, we performed a least cost route analysis - modeling the cost of moving through space where costs are a function of both the standard costs associated with movement, and of resistances that impede that movement (Eastman 1997). Based on expert opinion we derived the relative resistances of each cell according to the dominant land cover type, assuming that the easiest to cross is the area, marked as suitable habitat (Tab. 3).

The locations of favorite highway crossing sites depend on circumstances both in the immediate surroundings of the analyzed highway section and in the broader hinterland. For a 52 km highway section we thus considered a study area of 6.993 km^2. To simulate the movement of bears, 11 characteristic points of origin were chosen all over the core habitat, and the northern part of the Italian border was chosen as the destination. This agrees with the results of a habitat suitability analysis on the Italian side of the border (Corsi et al. 1998). Using the IDRISI function COSTGROW the accumulated cost surfaces were computed for each of the 11 points of origin. Then using the PATHWAY function the cheapest routes were determined linking each of the 11 points of origin with the destination area. The potential sites for wildlife bridges / underpasses were identified by overlaying the modeled migration routes with the highway map. These sites were subsequently validated by inspection on the ground and by comparing them with the locations of highway accidents involving bears in the years 1972 – 1996.

Results

The following decision tree was chosen as the best (Tab. 4). The accuracy of habitat / non-habitat classification was estimated as 84,9 % by a 10-fold crossvalidation. The decision tree shows only minor apparent effects of the noise in the training dataset and it is short enough to be comprehensible. Tests showed that very complex trees (resulting from less pruning and more attributes included) did not significantly improve classification accuracy on our data - in fact they mostly traced the noise. The chosen decision tree also mostly agrees with the domain knowledge: the main GIS layer describing the suitability of each cell for bear habitat in the study area is the percentage of forest, followed by both the density of human population and the elevation above see. Additional rules account also for differences in proximity to settlements, forest vegetation type and rural population percentage. However the induced tree did not account for the habitat patch size, which was evident after visualizing the results of study area classification based on the decision tree. Outside the core habitat area the visualized model showed some fragmented patches of habitat, which were clearly too small. A more realistic map of the habitat was obtained after a spatial filter with a 5.000 ha threshold was applied (Fig. 3b). Here the habitat is mostly confined to the large continuous forest areas along the Dinaric mountain range and in the Julian Alps. The spatial filter obviously reduced the commission errors, however there also appeared an omission of known habitat in the forest area south of the village of Razdrto, where bears have repeatedly been observed.

Based on the habitat map and land cover map, the potential dispersal corridors from 11 characteristic points within the core habitat area towards the Alps were identified. Irrespective of the point of origin, all 11 routes cross the highway at only 3 sites (Fig. 3b). Tests also showed that these sites moved very little, when we changed the relative resistances to movement for the respective land cover types. Assuming the validity of the input GIS data layers we therefore considered the 3 sites as the most convenient locations for the construction of the wildlife bridges / underpasses.

```
PERCENTAGE_OF_FOREST > 91:
:...DENSITY_OF_HUMAN_POPULATION <= 17: SUITABLE
:   DENSITY_OF_HUMAN_POPULATION > 17:
:   :...PROXIMITY_TO_NEAREST_LARGE_SETTLEMENT <= 2236: NOT_SUITABLE
:       PROXIMITY_TO_NEAREST_LARGE_SETTLEMENT > 2236:
:       :...DOMINANT_TREE_SPECIES in {0,11,12,21,22,31,33,34,35,
:                              36,37,38,52,53,54,55,56,57,61,62,63,65,66,67,68,72,73,
:                              74,75,77,78,81,82,83,84,85,86,89, 87,88}: SUITABLE
:           DOMINANT_TREE_SPECIES in {32,51,64,71,76,79}: NOT_SUITABLE
:           DOMINANT_TREE_SPECIES = 41:
:           :... FOREST_ASOCIATION in {0,11,12,21,22,23,24,25,31,32,41,42,43,
:                              51,52,53,54,61,62,71,72,73,74,81,84,91,92,93,94,95,
:                              101,111,113,121,122,123,131,132,141,142,144,151,152,
:                              161,171,172,181,182,183,191,192,201,202,203,204,211,
:                              212,221,222,223,224,225,226,231,232,233,234,235,236,
:                              241,242,243,244,251,252,261,262,263,264,271,273,274,
:                              275,282,283,213,133,134}: SUITABLE
:                FOREST_ASOCIATION in {82,83,112,143,272,281,70}: NOT_SUITABLE
PERCENTAGE_OF_FOREST <= 91:
:...ELEVATION <= 544: NOT_SUITABLE
    ELEVATION > 544:
    :...PERCENTAGE_OF_RURAL_POPULATION <= 1:
        :...DISTANCE_TO_FOREST_EDGE = 0: NOT_SUITABLE
        :   DISTANCE_TO_FOREST_EDGE in {1,2,3}: SUITABLE
        PERCENTAGE_OF_RURAL_POPULATION > 1:
        :...PERCENTAGE_OF_FOREST <= 11: NOT_SUITABLE
            PERCENTAGE_OF_FOREST > 11:
            :...FOREST_ASOCIATION in {0,11,12,21,22,23,24,25,31,32,41,42,43,51,
                              52,53,54,61,62,72,73,74,81,82,83,91,93,94,95,101, 111,
                              112,113,122,123,131,132,141,142,151,152,161,181,182,
                              183,191,192,201,202,203,204,211,212,221,222,223,224,
                              225,226,231,232,233,234,235,236,241,242,243,244,251,
                              252,261,262,263,264,271,273,274,275,281,282,283,213,
                              70,133,134}: NOT_SUITABLE
                FOREST_ASOCIATION in {71,84,92,121,143,144,171,172,272}: SUITABLE
```

Meaning of the included attributes: PERCENTAGE_OF_FOREST: estimated in a 1x1 km cell, based on the CORINE Land Cover database; ELEVATION: average elevation in meters in the 500x500 m cell, based on a 100x100 m digital terrain modell; PERCENTAGE_OF_RURAL_POPULATION: determined at a geographical subregion level (average area 400 km^2); DISTANCE_TO_FOREST_EDGE: discretely valued attribute: 0 means > 250 m outside forest, 1 means ≤ 250 m outside forest, 2 means > 500 m inside forest, 3 means > 1.000 m inside forest; FOREST_ASOCIATION: dominant forest association in a 1x1 km cell - discrete code value according to the Slovenian Forest Service nomenclature; DENSITY_OF_HUMAN_POPULATION: [residents/km^2] determined at a geographical subregion level (average area 400 km^2); PROXIMITY_TO_NEAREST_LARGE_SETTLEMENT: [m] distance of the 500x500 m cell center to the nearest settlement exceeding 5 hectares; DOMINANT_TREE_SPECIES: dominant tree species, estimated in a 1x1 km cell - discrete code value according to the Slovenian Forest Service nomenclature.

Table 4: The decision tree for the habitat suitability classification of the study area.

The 3 sites were validated by comparing them to the known crossing spots and to the recorded sites of bear - vehicle collisions. The site number 1 is situated in an area with the densest crossing spots and in close proximity to a seldom trafficked underpass. The identified potential corridor in the vicinity corresponds to the locally observed routes of dispersion. Additional electric fencing would have to be installed to avert bears from uncontrolled crossings in the vicinity. The site number 2 is located in an area of crossings recorded since 1992, 500 m from an existing forest road underpass, which is almost unused by traffic. However there are also other places on the respective highway section, which are known to be used by bears, including a forest road bridge and beneath the 593 m viaduct, located on the outskirts of the town of Postojna. This highway section is especially critical, because (1) it runs almost entirely along a railway, (2) it lies on the main bear dispersal route and (3) it cuts through an already bottlenecked habitat with the extensive core habitat in the background. Instalation of additional electric fencing is planned on this section to channel bears into existing underpasses and bridges. The site number 3 is located exactly beneath the existing 265 m long viaduct of Bandera. Recent field observations and absence of human disturbance on both sides of the viaduct, indicate that this location is suitable for bear crossing.

Discussion

Automated induction of the decision tree by machine learning method turned out to be a cost- and time-efficient way to form a knowledge base of the expert system for classifying the bear habitat suitability. We were thus able to maximize the information obtainable from the recorded bear sightings, which had been originally gathered for another purpose (population monitoring). The rules, structured into the induced decision tree, predict the suitability of habitat in the study area. However it must be born in mind that the decision tree does not necessarily reflect the actual behaviour of the bears - it only reflects the information inherent in the actual training dataset. Nevertheless the obtained tree mostly agrees with the domain knowledge. The spatial representation of the model in a GIS environment showed some inconsistencies, that could not be recognized from our decision tree alone. Mainly they were in the form of small habitat fragments, that could be afterwards filtered out with a GIS-based spatial filter, so that the final habitat model included only suitable areas within the relatively undisturbed Dinaric mountains and Julian Alps. A combined interpretation of habitat suitability modeling results, taking into account both qualitative aspects as presented by the induced knowledge base, and spatial aspects as visualized by GIS, therefore turned out as advantageous. Inducing very large decision trees was avoided, because tests on our data showed that very complex trees did not significantly improve habitat classification accuracy - they mostly traced noise in the training dataset. The decision tree also unnecessarily inflated when all available attributes were included or when a lot of them had discrete values.

Considering the spatial resolution of the model, independent field observations generally confirmed the validity of the identified sites for the wildlife bridges / underpasses. The model offered a coarse approximation, based on ecological aspects only. Before any final decision, also the technical or financial feasibility of building such objects should be considered. But since all potential crossing sites are within reach of existing (non wildlife-friendly) crossing objects, a possibility of adapting these objects is worth considering. Of course only providing suitable crossings will not be enough - measures will be needed to channel the movement of bears across highway and to stop them from climbing the fence. But regardless of the type of the crossing object, an adequate land use management, aimed at conserving / enhancing the quality of habitat in the surrounding area, will be crucial.

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