HANDBOOK FOR INTEGRATING THE BEAR HABITAT SUITABILITY AND CONNECTIVITY TO SPATIAL PLANNING

Prepared within the framework of the LIFE DINALP BEAR project
Ljubljana, April 2019

LIFE
DINALP
BEAR

CIP - Kataložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

599.744.2:591.51
711.2/.4(035)

HANDBOOK for integrating the bear habitat suitability and connectivity to spatial planning : prepared within the framework of the Life Dinalp Bear project / [authors Hubert Potočnik ... [et al.] ; editor Hubert Potočnik ; authors of photograps Hubert Potočnik ... [et al.] ; translation Prevekso Jeziki]. - Ljubljana : Univerza, 2019

Izv. stv. nasl: Priročnik za vključevanje povezljivosti in primernosti prostora za medveda v prostorsko načrtovanje

ISBN 978-961-6410-58-8
1. Potočnik, Hubert
299505664

CONTENTS

1. INTRODUCTION

One of the most radical changes to the landscape of Europe over the past centuries has been the creation of vast urban and agricultural areas and subsequent extension of infrastructure networks. Towards the end of the 20th century, expansion of the major railway and road networks slowed, but did not cease. At the same time, an ever-denser network of minor roads (e.g. for forestry), tracks and trails has extended into the last wildernesses areas of Europe.

Habitat for any species is divided into "habitat patches", areas with favourable conditions for the species that are separated by "matrix", areas where individuals can move through but will not permanently reside, and "barriers", through which individuals are more or less difficult or even unable to pass. This fragmentation can be caused by natural features like rivers, high mountain ranges or seas and divides species range into populations and subpopulations. However, human developments are changing the landscape, decreasing habitat, introducing new barriers and pushing fragmentation to the point where it is currently recognized as one of the main threats for many endangered species and a critical obstacle to species recovery.

Loss of natural environment to increasing urban and agricultural areas has been one of the biggest changes caused by humans in Europe. On the left image we can see that the most habitat is lost in the fertile river valleys and lowlands. On the right image, we can see how road infrastructure has affected fragmentation and habitat connectivity. (Potočnik H.)

The brown bear, a charismatic large carnivore, is recovering in most of the European populations as a result of different management strategies applied on, often, well diverse scenarios of different intensities of human-pressure (Chapron et al. 2014). However, the viability of recovering populations and the well-being of the populations that have best withstood human pressure depend very much on appropriate decision-making in conservation strategies. Consequently, it is important to improve the understanding of the requirements of bears in the current context of population recovery and likely expansion, including the specific spatial needs for the species.

Traffic network is one of the main threats to viable populations of Brown bear in Europe. (Hlačer J.)

In lowlands and river valleys (like between Cerknica and Planina), railways are often laid parallel with motorways and other roads and represent major barriers for wildlife. (Črtalič J.)

In valleys such as between Cerknica and Planina railway lines, motorways and other roads often lie close together at the valley bottom. Together they form strong barriers.

Re-colonization of Eastern Alps through natural expansion of bear individuals from the Dinaric population in Slovenia and Croatia is one of the priorities of bear conservation in Europe. Connectivity between habitat patches is a critical issue for long-term survival of any wildlife population, as it directly affects not only its dynamics and chances of long-term survival, but also its possibilities for expansion. This makes improving of habitat connectivity between the Dinaric Mountains and the Alps, which will ensure the adequate number of dispersals and maintain gene flow, critical for establishing a viable bear population in the Alps, but very challenging considering the needs and desires of humans. Increased urbanization of bear inhabited areas and development of large transport infrastructure such as highways has accentuated this challenge in Slovenia and the neighboring countries over the recent years. The cheapest and most effective way to preserve connectivity is to prevent development in small, critical areas that connect large habitat patches. An effective way to do this is to provide correct information for environmental impact assessment (EIA) that would include habitat connectivity for the bear in spatial planning, and conserve the most critical locations. This is becoming increasingly important as these locations are typically located on cheaper land between already developed areas, and are often the most desirable locations among investors for expansion of industrial and urban areas. While legislation and procedures concerning spatial planning are well developed, there is still a gap in expert knowledge when it comes to ensuring connectivity between habitat patches for large carnivores. With this handbook we will attempt to fill this gap and popularize the large carnivore habitat connectivity issue among the experts and companies dealing with spatial planning and environment impact assessments

The consequences for wildlife of constructing transport infrastructure include traffic mortality, habitat loss and degradation, pollution, altered microclimate and hydrological conditions and increased human activity in adjacent areas. All these cause considerable loss and disturbance of natural habitats. In addition, roads, railways and waterways impose movement barriers on many animals, barriers that can isolate populations and lead to long- term population decline. Habitat fragmentation, the splitting of natural habitats and ecosystems into smaller and more isolated patches, is recognised globally as one of the biggest threats to the conservation of biological diversity. Habitat fragmentation is mainly the result of different forms of landuse change. The construction and use of transport infrastructure is one of the major agents causing this change as well as creating barriers between habitat fragments. The steady increase in animal casualties on roads and railways is a well- documented indicator of this problem. On the other hand, barriers causing habitat fragmentation have a long-term effect that is not that easy to detect.

To obtain an ecologically sustainable development and especially transport infrastructure, mitigation of these adverse effects on wildlife needs a holistic approach that integrates both the social and ecological factors operating across the landscape. Hence, one of the challenges for ecologists, infrastructure planners and engineers is to develop adequate tools for the assessment, prevention and mitigation of the impacts of infrastructure.

Statistics show that the number and length of motorways in Europe in last 30 years have increased by more than three times (EuroNatur, 2010). With increasing traffic and road development, more pressure is placed on wildlife. New roads are further dividing landscape into increasingly smaller fragments. This creates a barrier and affects species living in such areas. Reduced ability to move around in search of food, mates and new habitat can lead to isolation, loss of genetic diversity and in the long term regional extinction. Smaller patches of land are not able to support the same number of individuals and species as can big unfragmented habitats. Depending on the traffic intensity and the presence of fences, the barrier can be physical or behavioral when animals are actively avoiding areas near roads. By dividing habitats into smaller fragments, the area of habitat edge is also being increased. While edges can be an important habitat for generalist species, they can also aid the spread of invasive species or act as a barrier for other and they rarely have the same value as natural corridors as conditions are rarely constant over longer distances.

Fenced highways create big barriers and add to the fragmentation problem. A1 motorway Zagreb – Split cuts Dinaric bear habitat. (Huber Đ.)

Traffic related mortality is one of the most important causes of bear mortality, too. It can create population sinks in areas critical for connectivity, reducing migration and gene flow, and limiting spatial expansion of the species. It is an important factor limiting natural recolonization of bears into the Alps and establishment of a viable, well connected Alpine-Dinaric meta-population in southern Europe. The problem of traffic related mortality is exacerbated in bear corridors connecting Dinaric Mountains with Alps, where bear-vehicle collisions represent the main cause of mortality, creating local population sinks. In Slovenia and Croatia, a detailed analysis of the effects traffic has on bears has been performed, both from the perspective of the population in general as well as the influence it has on population expansion towards the Alps. A combination of factors can cause a bear climbing a highway fence, including unprotected garbage or other road kill attracting bears. In Croatia, the impact of unprotected garbage bins on bear traffic mortality has been assessed on highways.

Road development affects the environment itself as it disturbs and changes the landscape. Often even areas further away from road are affected, either by pollution (salts, chemical spills), noise or vibrations. Increased light affects growth regulation in plants, disturbs breeding and foraging behavior of animals. After road construction, new settlements or industrial areas will often follow and cause the construction of local access roads. Thus habitat is further fragmented and human presence even further disturbs wildlife habitats.

To avoid or mitigate these negative effects road infrastructure can be made more permeable by creating passages for wildlife to cross the barriers to suitable habitats. In addition to conservation of species, wildlife crossings provide socio-economic benefits. Driver safety is enhanced when a better alternative is provided for wildlife crossing. Removing wildlife from roadways also reduces the number of collisions, human fatalities, injuries and damage to property (Chistolm et al. 2010).

While habitat fragmentation is increasingly taken into account when new infrastructure is planned, there remain many existing stretches of road and railway where mitigation measures are badly needed. The impact of existing infrastructure can change when new infrastructure is built, further increasing the need for mitigation measures. When designing measures to counteract habitat fragmentation, the focus should, therefore, be on the impact of the infrastructure network as a whole.

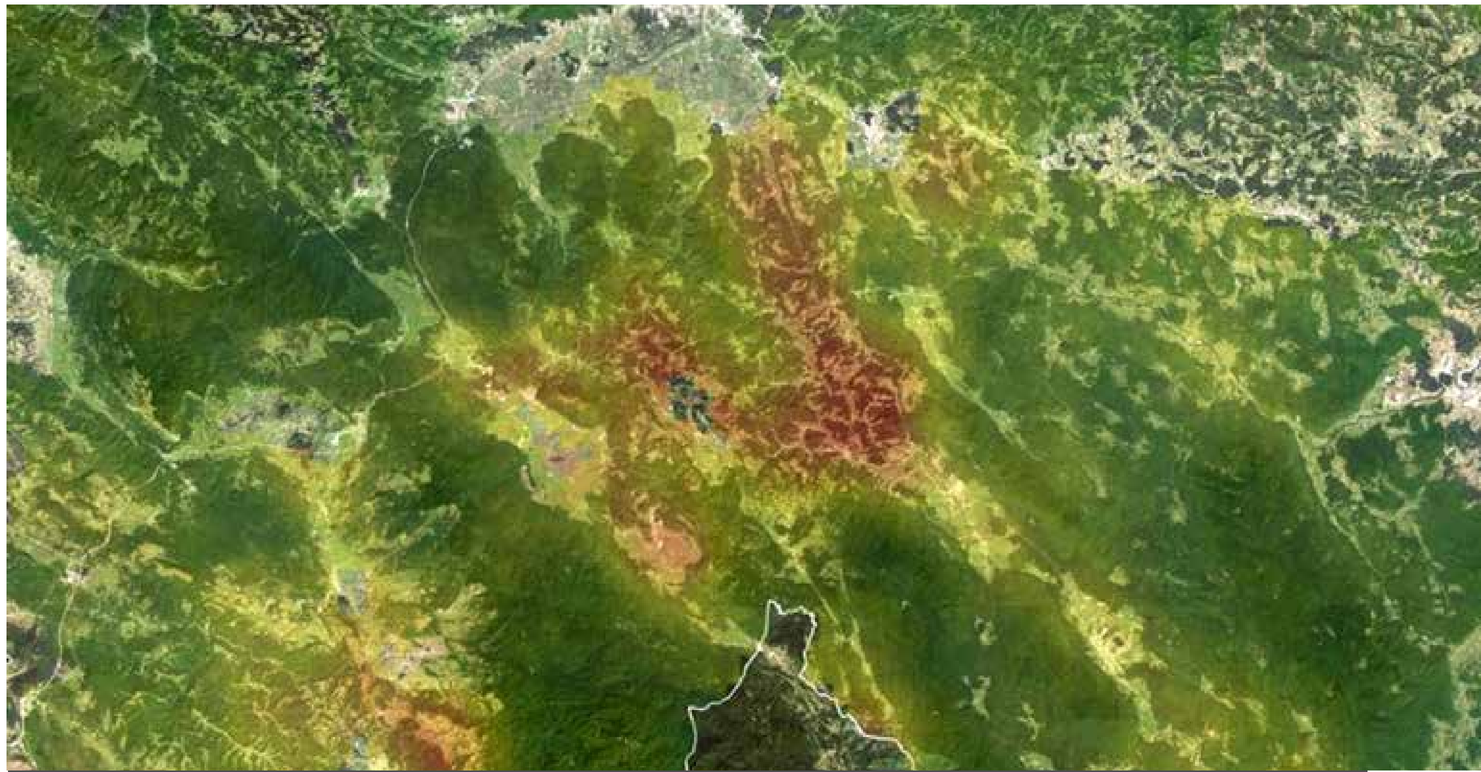
There is a difficult balance between finding broad general solutions on the one hand, and more detailed local or regional solutions on the other. With this background, it is important to emphasize that there are no 100% correct solutions. There are two ways to tackle this problem – restoration/mitigation/compensation and prevention. Prevention is even more effective as it costs nothing. As large new developments typically require an environmental impact assessment studies (EIA), much of further fragmentation for the species could be prevented if critical areas for habitat connectivity are identified, and appropriate guidelines are given to people performing the EIA. However, such assessments must be based on a solid understanding of the landscape connectivity for the brown bear, which is what we aim for. The advice provided here is based upon the accumulated knowledge of a broad range of experts from the participating countries. It remains necessary to adapt and adjust measures to the local context, as well as to the specific needs and possibilities of the location. The guidelines itself are, therefore, no alternative for the advice of local experts such as ecologists, planners and engineers and should be used in conjunction with their advice

Traffic mortality is one of the main causes of death for Slovenian and Croatian brown bears (second to hunting). People are also in danger when collisions occur. (Masterl M.)

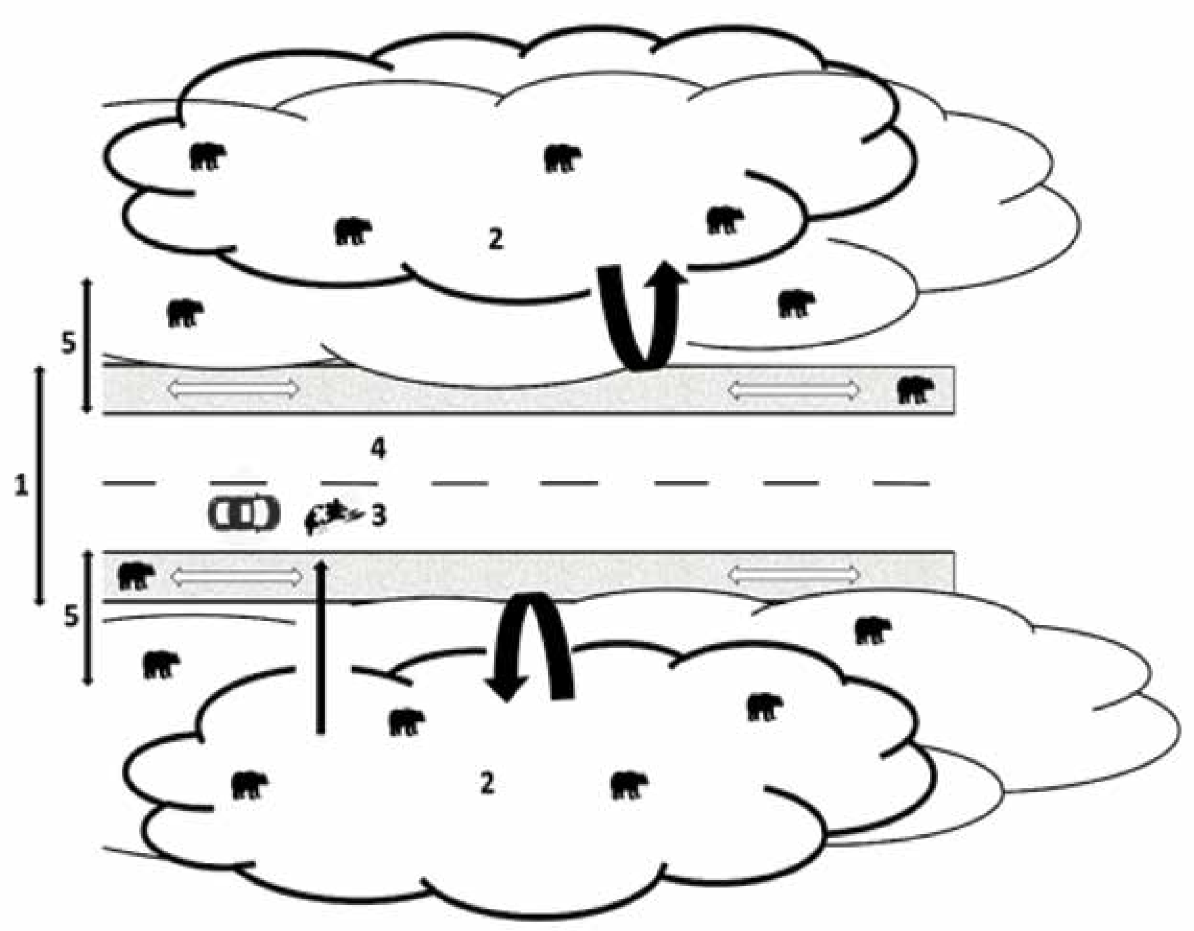
2. DEFINING HABITAT FRAGMENTATION

Transport networks, urban areas as well as agricultural landscapes divide natural habitats into small isolated patches and create barriers between the remaining patches. This can have two primary effects on species; firstly, it can reduce the size of habitat patches so much that they can no longer support viable populations of important species; and secondly, it can result in the remaining patches being so isolated from each other that individuals have a low chance of moving between patches. Being unable to move between patches renders species vulnerable to local and regional extinction. Through these processes, habitat fragmentation by transport networks and consequential secondary developments have become one of the most serious global threats to biological diversity. Although human activity started to fragment nature many centuries ago, the rapid increase in density of transport networks during the 1900s and the effect of increased accessibility have greatly accelerated this impact.

Busy roads (especially highways) have a significant effect on the surrounding natural environment. One of the most important effects is the fact that, for a number of organisms, they represent impassable barriers. Other effects include a loss of habitat during road construction, the killing of animals by passing vehicles, contamination of the environment, and various types of disturbance (noise, etc.). The indirect influences of roads are also significant, such as an increase in urban pressure in areas not previously accessible, secondary construction along roads, etc. The barriers created by roads represent long lines that animals are unable to bypass. Major roads, therefore, cause habitat fragmentation as well as the fragmentation of the population of resident species. The increasingly dense highway network then turns the originally open landscape into a system of isolated 'islands'. Due to habitat fragmentation, populations are then exposed to the so called 'island effect'. Small isolated populations generally find it more difficult to handle natural fluctuations in numbers caused by climatic changes, natural disasters, epidemics, etc.; an insufficient genetic diversity may



Fragmentation can increase human – wildlife conflict. Map of human – bear conflict intensity for Slovenia shows area with most conflict in red (Jerina et al. 2015a).



Schematic representation of the primary ecological effects of transport infrastructure. The label numbers relate to the primary ecological effects listed above.

also become apparent in the long-term. At a certain level of density of the highway network, this becomes a survival problem for some species, especially in cases where a relatively small number of individuals inhabit an extensive area. Logically, some species of large mammals will then be among those most endangered. Smaller mammals are usually less affected by the existence of highways, particularly as populations living in those sections of the landscape defined by the highway network are usually sufficiently numerous, and the highway effect is therefore less obvious. Also, smaller mammals usually find sufficient opportunities to cross highways through, for example, sluice culverts, which cannot be used by large animals. Highways, therefore, present a real and crucial problem for large mammal populations.

Transport infrastructure has both direct (primary) and indirect (secondary) effects on nature. It is possible to distinguish between five major categories of primary ecological effects that negatively affect biodiversity plus a group of indirect ecological effects: (1) Habitat loss. (2) Barrier effects (3) Wildlife mortality - collisions between vehicles and wildlife (4) Disturbance and pollution and (5) Ecological function of edges of infrastructure. In practice, these effects usually interact and may significantly increase their negative impact through synergistic effects. The consequences of loss and deterioration of wildlife habitat, barrier effects, isolation, and disturbance can be summarised by the term fragmentation.

Loss of wildlife habitat

The direct impact of road construction, urbanization and cultivation of natural environment is the physical change in land cover along the route and areas as natural habitats are replaced or altered by infrastructure and urban/agricultural areas. The impact of this net loss of natural habitat is made worse by disturbance and isolation effects that lead to an inevitable change in the distribution of species in the landscape. Locally, however, the allocation of space for infrastructure will necessarily lead to conflicts with other landuses such as nature conservation, recreation, agriculture or human settlement.

Barrier effects

The barrier effect, especially of (fenced) roads and railways is probably their greatest negative ecological impact. The dispersal ability of individual organisms is one of the key factors in species survival. The ability to move around a landscape in search of food, shelter or to mate, are negatively impacted by barriers that cause habitat isolation. Impacts on individuals affect population dynamics and often threaten species survival. The only way to avoid the barrier effect is to make infrastructure more permeable to wildlife by means of fauna passages, adapting engineering works or by the management of traffic flows. Carefully selecting the route of the road through the landscape can minimise the barrier problem.

Physical barrier: For most of the larger mammals, transport infrastructure becomes a complete barrier only if fenced or if traffic intensity is high. Behavioural barrier: Many larger wildlife species are known to avoid areas near roads and railways related to the degree of human disturbance (traffic density, secondary/urban development). Other animals, such as small mammals and some forest birds, exhibit behavioural avoidance patterns particularly associated with crossing large open spaces. The disturbance from noise is mainly influenced by the type of traffic, traffic intensity, road surface properties, topography, rail type and the structure and type of the adjacent vegetation. Geological and soil characteristics influence the magnitude and spread of vibrations. Some species avoid noise-disturbed areas. Artificial lighting can affect growth regulation in plants, disturb breeding and foraging behaviour in birds or influence the behaviour of nocturnal amphibians. Lights can also attract insects (mercury lamps) and, in turn, increase

To prevent or mitigate the barrier effect of fenced highways for wildlife, wildlife crossings should be implemented to increase permeability. (Huber Đ.)

the local densities of bats along roads resulting in increased bat mortality. The movement of road and rail traffic is thought to disturb several sensitive wildlife species such as wild reindeer and red deer.

The alignment of two or more forms of transport infrastructure along the same corridor (in close proximity) can be beneficial for some species as only one barrier is created. It is, therefore, often advantageous to place two or more parallel routes as close as possible especially in the case of multimodal transport corridors (roads and railways). The disadvantage of multimodal transport corridors is that they can strengthen the barrier effect to some species.

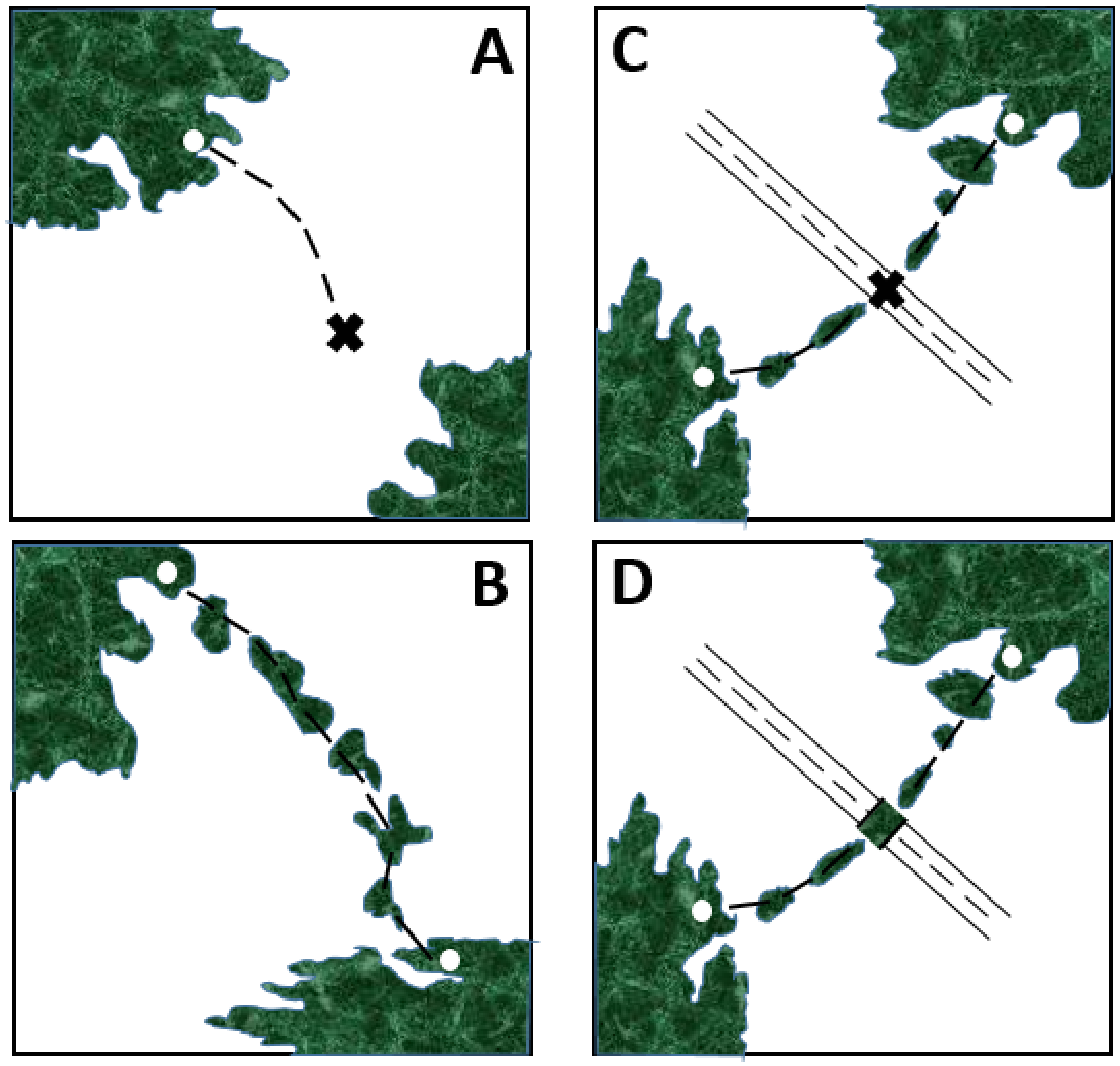
The value of infrastructure verges is a much debated topic. They can be important habitats for some species of wildlife, but they can also lead animals to places where mortality is increased or aid the spread of alien species. Verges can provide links in an ecological network and function as corridors for movement, especially in agricultural landscapes. Their function depends on their geographical location, vegetation, adjacent habitat, management and type of infrastructure. Through careful management, infrastructure verges may complement and enrich landscapes where much of the natural vegetation has been depleted. Nevertheless, verges are unable to fully replace natural habitat due to disturbance and pollution effects. As a result, the species composition in roadside communities is often biased towards a higher proportion of non-native and ruderal species.

The best practice approach for planning new or upgrading existing transport infrastructure adopts the following principles for coping with the threat of habitat fragmentation.

AVOIDANCE → **MITIGATION** → **COMPENSATION**

The basic philosophy is that prevention is better than cure in avoiding the negative effects of habitat fragmentation. Where avoidance is impossible/impractical, mitigation measures should be designed as an integral part of the scheme. The former requires a thorough understanding of habitat available to target species (e.g. bears) and causes of fragmentation to identify the areas where the highest increase in connectivity can be achieved at the lowest costs. Where mitigation is insufficient or significant residual impacts remain, then compensating measures should be considered as a last option. Although the focus is mainly on new roads, the principles should also be applied to existing roads where repair and maintenance, relationships with other fragmentation sources and the use of existing engineering works should be examined.

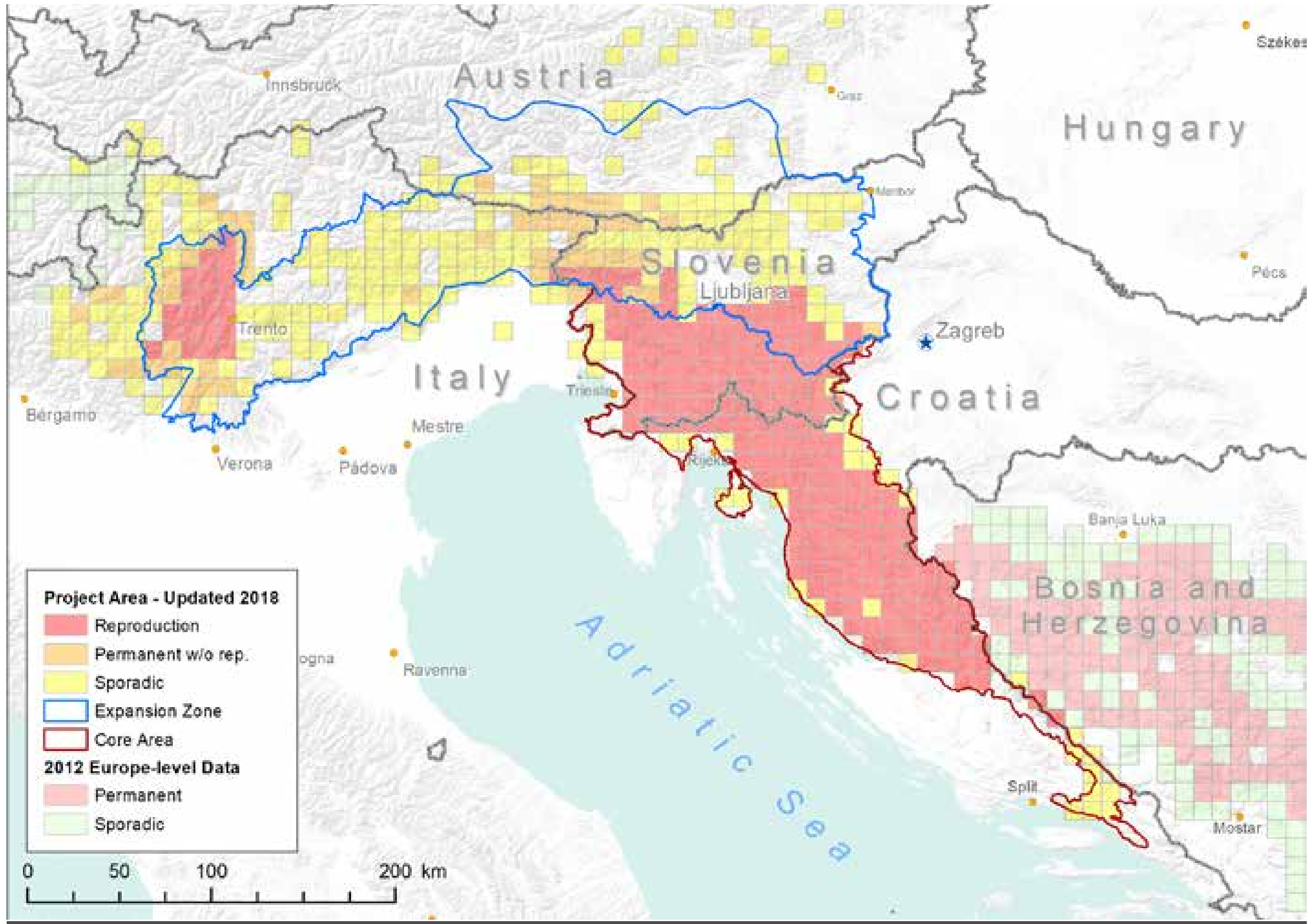
Changes in landuse, human settlement patterns or industrial development induced by the construction of transport infrastructure are secondary effects. New settlements and housing estates may follow the construction of new regional roads and in turn induce the construction of local access roads. These secondary effects are usually outside the responsibility of the transport sector, but should be considered in Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA). One of the main secondary threats associated with infrastructure development is the increased degree of human access and disturbance. Networks of small forest roads provide hunters and tourists access to otherwise undisturbed wildlife habitats. Some design specifications have purposely not included car parking facilities and lay-bys to minimise disturbance to sensitive habitats. However, once infrastructure development has occurred it is very difficult to limit access to adjacent land even if it is of high conservation value. Plans to manage increased access should therefore be drawn up during the planning stage and implemented in association with the infrastructure development.



The effect of natural corridors and road infrastructure on movements of animals between suitable habitat patches:
A. In open landscapes without ecological corridors, species may not be able to move between habitats.
B. Small fragments of suitable habitat may serve as stepping stones connecting distant habitat patches.
C. Ecological corridors in combination with roads may attract animals but direct them towards the road where they might be killed when attempting to cross.
D. Mitigation measures such as wildlife passages can help to re-link ecological corridors.

3. BROWN BEAR POPULATION STATUS, DISTRIBUTION AND CONNECTIVITY

Croatia and Slovenia are among the few EU countries providing habitats for three species of large carnivores, including brown bear. They are listed in Annexes II and IV of the Habitats Directive (92/43/EEC) and specifically addressed on the IUCN Red lists and by international conventions (e.g. Bern Convention). European commission adopted the list of Key actions for large carnivores to secure their populations long-term well-being. Bears live in low densities, occupy large home ranges thus are susceptible to fragmentation of their natural habitats. Fragmented populations are prone to decline in numbers followed by genetic depression and extinction. The brown bear population present in SE Alps and Northern Dinarics in Slovenia and Croatia is part of the Alpine-Dinaric-Pindus population with its area spanning over Austria, NE Italy, Slovenia, Croatia, Bosnia and Herzegovina, Macedonia, Montenegro, Kosovo, Albania and Greece (Swenson et al. 2000). Habitat range in Slovenia and Croatia for both species stretches over very large area and includes 20 designated Natura 2000 sites as core areas for bear reproduction and territories establishment. In 2007 the minimum bear population size for Slovenia, was estimated to 424 (383-458) bears. The methodologically very similar estimate for 2015 obtained in 2017

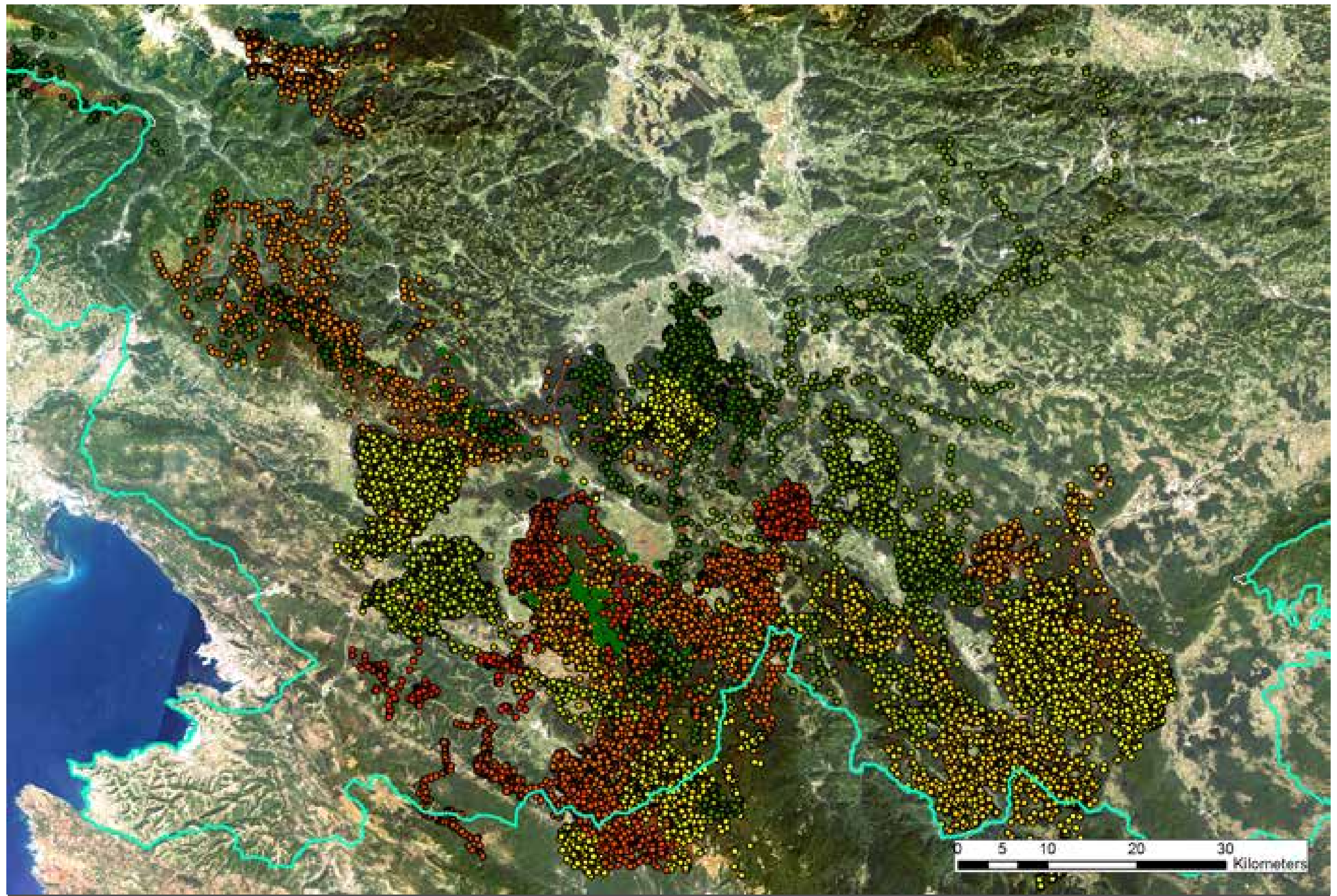


Bear distribution in SE Alps and Dinaric Mountains – updated 2018 (status between 2012 and 2017). Permanent presence, reproduction – areas where cubs were confirmed within the last three years; permanent presence, no reproduction – areas where bears have been present for at least three years over the last five years; sporadic presence – areas where bear presence has been documented for fewer than three seasons in the last five years period. (Skrbinšek et al. 2018, LIFE Dinalp Bear)

was 599 (545-655) bears, or a 41.3 % increase over the period of 8 years (Skrbinšek et al. 2017). In the same study minimum bear population in Croatia was estimated to 793 (702-928) individuals.

The home range size of individual bears is a basic biological parameter that enables us to understand the life strategy of the species. It is also important for management because conflict mitigation measures vary considerably depending on whether home range size is relatively small compared to the size of available forest patches with no human settlements or whether each individual covers an area large enough to include areas with regular human presence – as was observed in our case. Mean bear home range size in Slovenia was estimated at 350 km2 (Jerina et al. 2012) and in Croatia 366 km2 (Huber et al. 2008) (using the 100% minimal convex polygon method), which is comparable with the home range sizes of bears from other populations existing in similar environments. On average, male home range size was 4 times larger than that of females. The data indicated that from the perspective of a bear even the largest forest patches in Slovenia are relatively small (e.g., the largest Slovenian forest complex on the Snežnik plateau and Javorniki covers approximately 500 km2, which is even less than the home range of some bears). Therefore, it is not surprising that the home ranges of almost all monitored bears also included some human settlements. This is one of the key facts for bear management, as it shows that in Slovenia and Croatia we do not have regions available where bears can live in isolation from humans.

Habitat suitability for bears in Europe agree very much on general patterns in habitat selection: bears prefer forest and avoid open areas and human settlements as well as the vicinity of dominant human infrastructures. Additionally, they seem to prefer an altitude somewhere in the middle between the bottom of the valleys and the natural timberline. This probably is not a direct function of altitude, but a compromise between the avoidance of disturbances by humans next to the valley bottoms and the

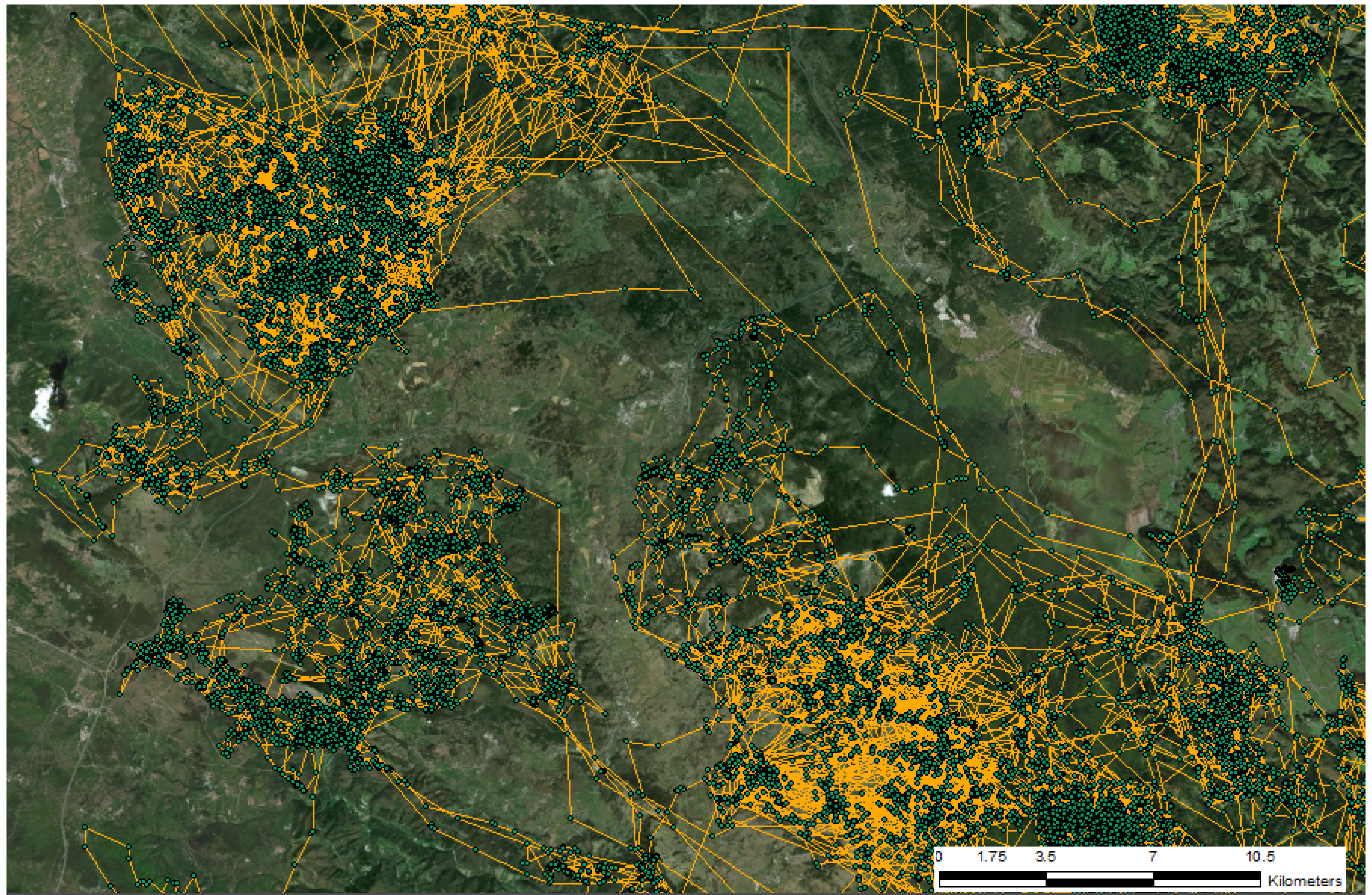


Telemetry movement data of GPS - collared bears (33) in Slovenia. (Jerina et al. 2012) decreasing food availability with increasing altitude. Studies have shown that the large forested areas in the Dinaric Mountains are of high suitability for bears. Beech trees are very common and provide high energetic food in autumn in mast years. Other natural food sources for bears are plenty, but may differ from region to region. Worthwhile to mention are ants (and wasps) which provide an important protein source during summer that is available almost everywhere. Additionally, baiting and feeding of ungulates with corn is very common and also bears profit from this practice. In some countries, there is also intensive artificial feeding primarily targeting bears.

Habitat connectivity in Dinaric Mountains

Habitat fragmentation and degradation are currently the major threats to bears. Fenced highways and motorways are the prominent cause of large scale habitat fragmentation. Most of Western Europe does not have any more adequate habitat patches to support viable large carnivore populations.

Coming from south to north, the highway Zagreb-Rijeka is the first major barrier bears face. This barrier can be crossed by bears quite well due to tunnels, bridges and one green bridge, but poses an additional risk for mortality of bears by traffic accidents. Further north the border between Croatia and Slovenia is partly fenced against refugees. At the moment the fence covers only 10% of the border in suitable bear habitat, but dependent on future measures deriving from refugee and asylum policy this barrier might become stronger. The next and most important barrier south of the Alps is the highway and railway Ljubljana-Postojna (and further to Trieste). These two just cut through the main bear core area in the south of Slovenia and the best corridor to the Alps. The importance of the barrier has been shown by following many radio/GPS-collared bears and also by the genetic studies. Especially in the area of Rakek and Unec this barrier is the major source of mortality (stronger than hunting). The area northwest of this highway (Nanos, Hrušica and Trnovski gozd) forms the most suitable corridor between the Dinaric Mountains and the Alps. East of Ljubljana there is another corridor connecting both mountain ranges, but bears have to cross very fragmented and quite flat areas before they reach the Alps. Both corridors have been used by bears. During construction of the highways only limited permeability measures were implemented, encompassing 13 green bridges constructed in CRO and none in Slovenia.



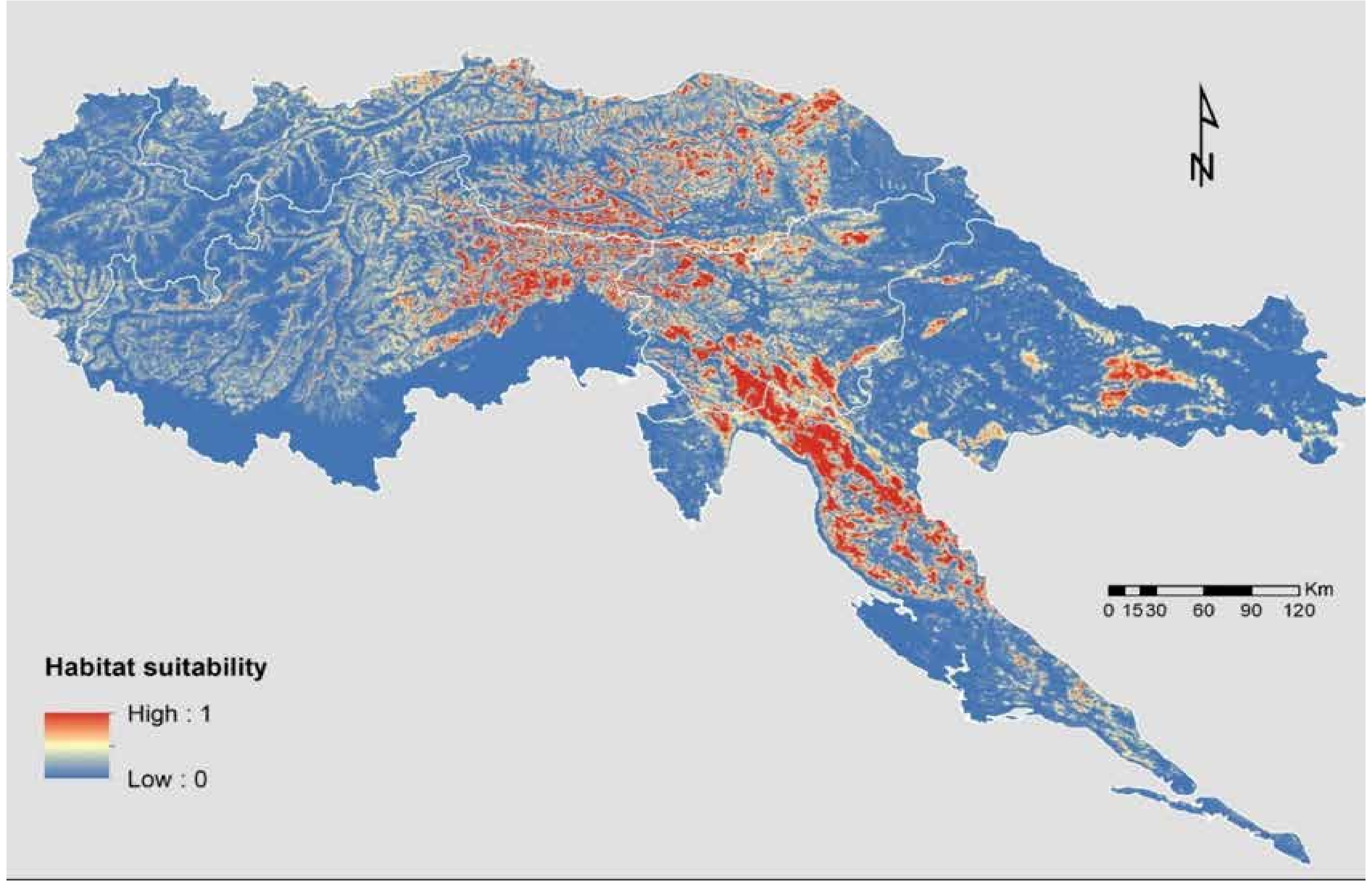
Example of bear movement between suitable habitat patches in Slovenia (Jerina et al. 2012).

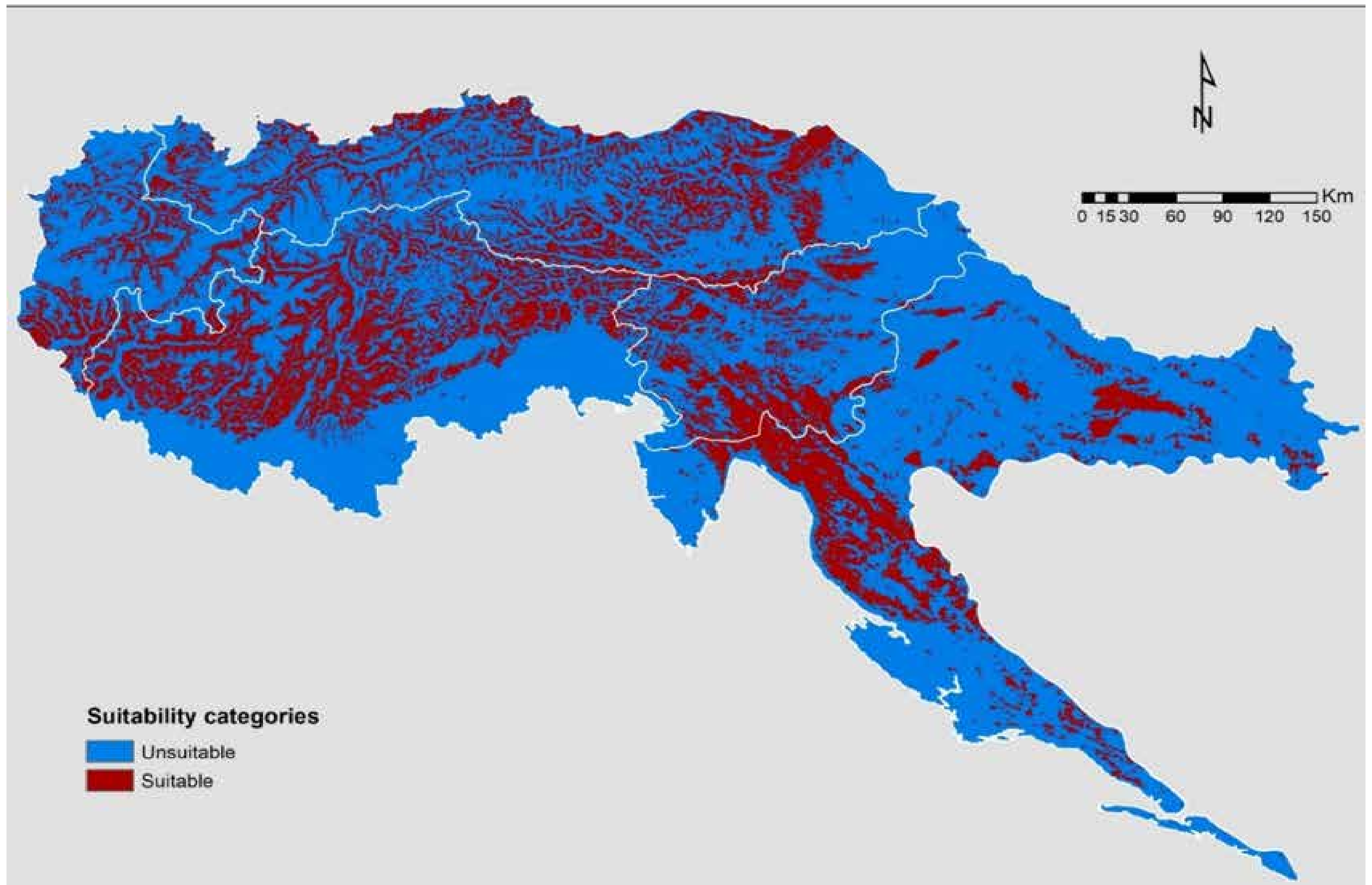
Habitat connectivity in the Alps

Naturally, the Alps are divided into northern and southern part by the main ridge of the Central Alps. This is a natural barrier and can be crossed by bears on many places, but hinder them by vast areas of rocks and glaciers without much vegetation. Beside the central part, the Alps provide very good habitat, especially in the Northeast. Bears in this area (of a former introduced and later extirpated population) have shown one of the highest reproductions ever found in brown bears in the wild worldwide. As a general pattern, in the Eastern Alps the North is less fragmented by unforested agricultural areas as the South, but both areas show contiguous suitable habitat for bears. There is one large area of destroyed habitat, i.e. the "Klagenfurter Becken" in southern Carinthia. This is full of settlements and disturbances by humans are too frequent for bears to settle in permanently. But bears have shown to be able to cross this area. The Alps are crossed by many highways and railways, but due to the rough terrain they usually have a lot of tunnels and bridges and do not form significant barriers. But there are two exceptions: The Inn valley (Inntal) and the Adige valley (Val d´Adige/Etschtal). Both valleys are wide and the valley bottoms are more or less unforested and used for settlements and agriculture. Additionally, highways and railways follow these valleys. The Inn valley is located in the north (Tirol, Austria) and represents a major barrier from Landeck downstream to the northern edge of the Alps in Bavaria (Germany). The Adige valley between Meran/Merano and the southern edge of the Alps near Verona divides the Central Italian Alps into two halves. West of this valley there is the only reproducing bear population in the Alps. Male bears have shown to be able to cross this valley and to expand to the east. The area east of this valley (regions of Veneto and Friuli Venezia Giulia) is not a classical corridor rather than a large suitable area that acts currently as corridor between the bear populations in Trentino and Slovenia.

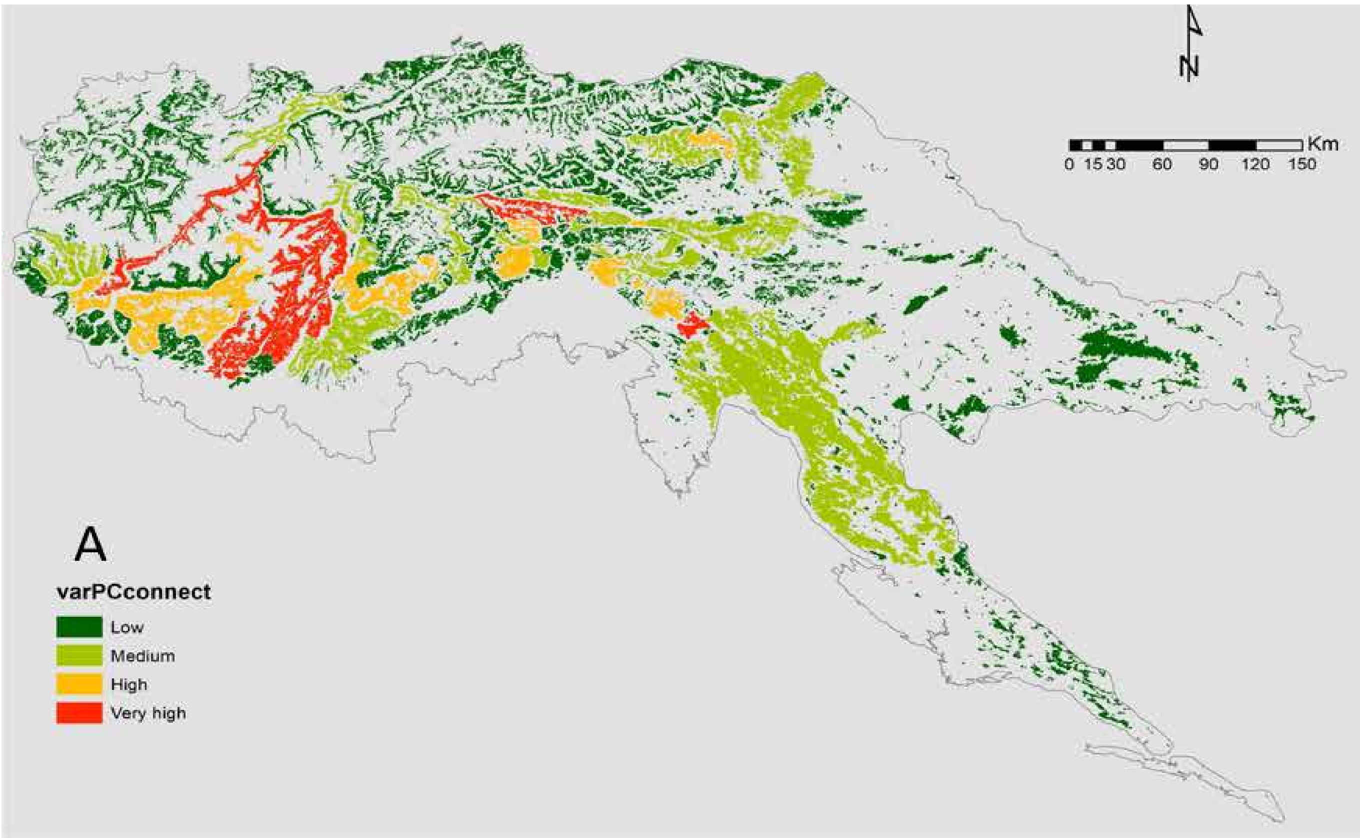
Analyses of the bear habitat suitability and spatial connectivity in the Central-eastern Alps and Dinaric Mountains

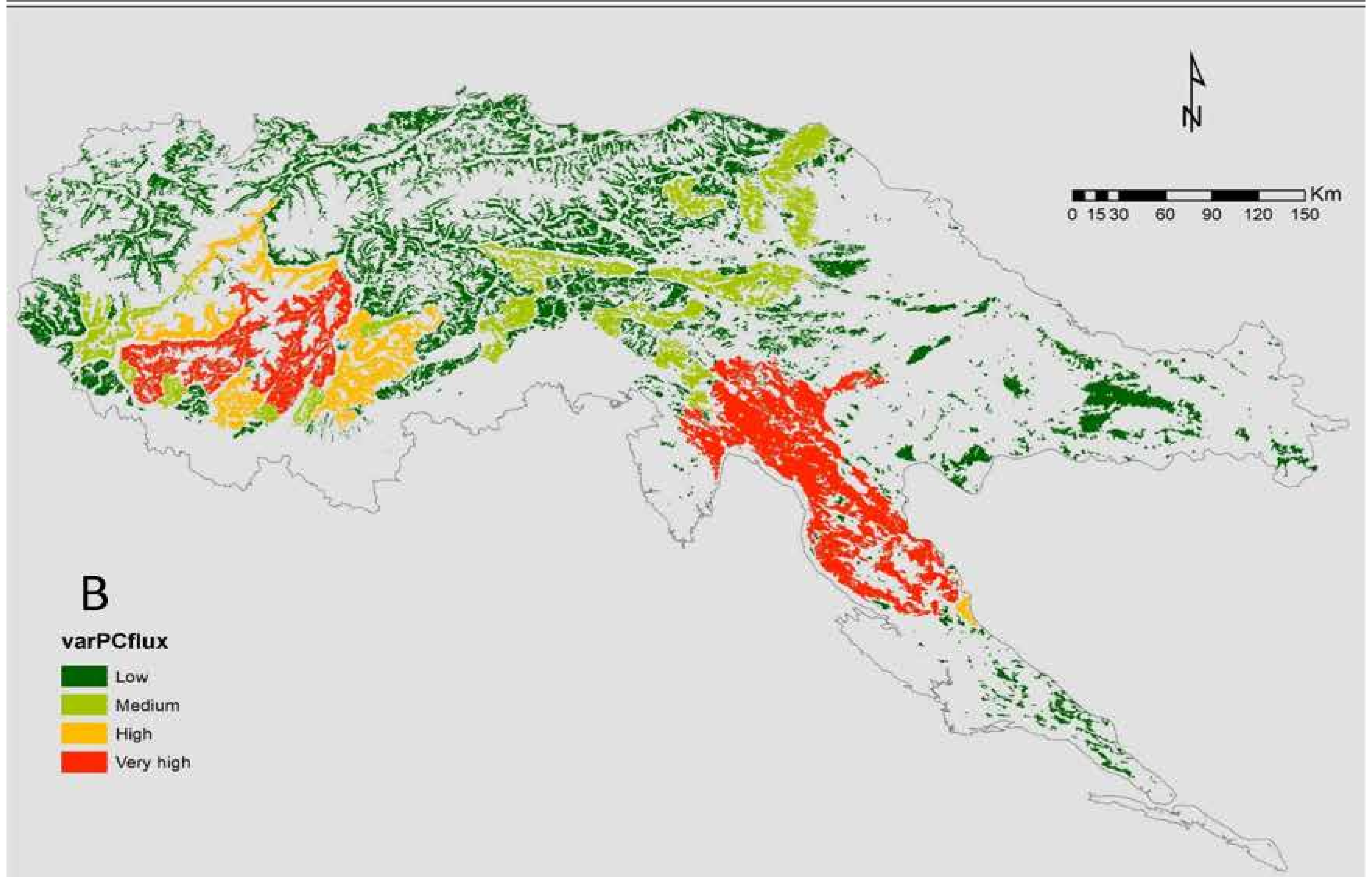
To foresee conflicts with humans and to facilitate decision-making, spatially explicit research is required to identify potential habitats and the connectivity of fragmented bear populations. Predictions on the potential habitats suitable for bears and for the connectivity among populations are capable to assist decision-making on conservation plans. Brown bears have been tracked using GPS collars for the last decade in the Alps and the Dinaric Mountains. Thus, rich location datasets on tracked bears were available to combine and to address questions on the space use by the species at broader geographical scales involving different European countries; specifically, Slovenia, Croatia, Austria, Italy, and Switzerland. A thorough analyses on bear habitat suitability and spatial connectivity was conducted within LIFE DINALP BEAR Project (Recio et al. 2018). First, they conducted multiscale modeling and identified drivers shaping the space use of three bear populations/demographic units ("Trentino-Swiss", "pre-Alps", and "Dinaric"), and across three scales of space (population distribution, home range establishment, and use of individual home range). Secondly, they performed an analysis of the connectivity patterns of suitable habitat patches (nodes) to identify the





Habitat suitability maps show probability that habitat is used by bears. Above: Continuous Habitat suitability model, values in interval from 0 to 1. Below: Binominal habitat suitability model, separates suitable versus unsuitable habitat for the bear. (Recio et al. 2018)





Importance of habitat patches for population connectivity of bear in SE Alps and Dinaric Mts: Above: Map of habitat connectivity (varPCconnect), indicating importance of block (group) of habitat patches as a »stepping stone« for connectivity to other blocks of habitat patches. Below: Connectivity map between habitat patches (varPCflux), indicating how good particular block of habitat patches is connected with habitat patches that form the block (population patch). (Recio et al. 2018) potential importance of each node to contribute to individual mobility, survival, and population connectivity. Lastly, to support further environmental impact assessment analyses, they identified the most plausible least-cost paths connecting different areas of the same large patch with itself and surrounding patches..

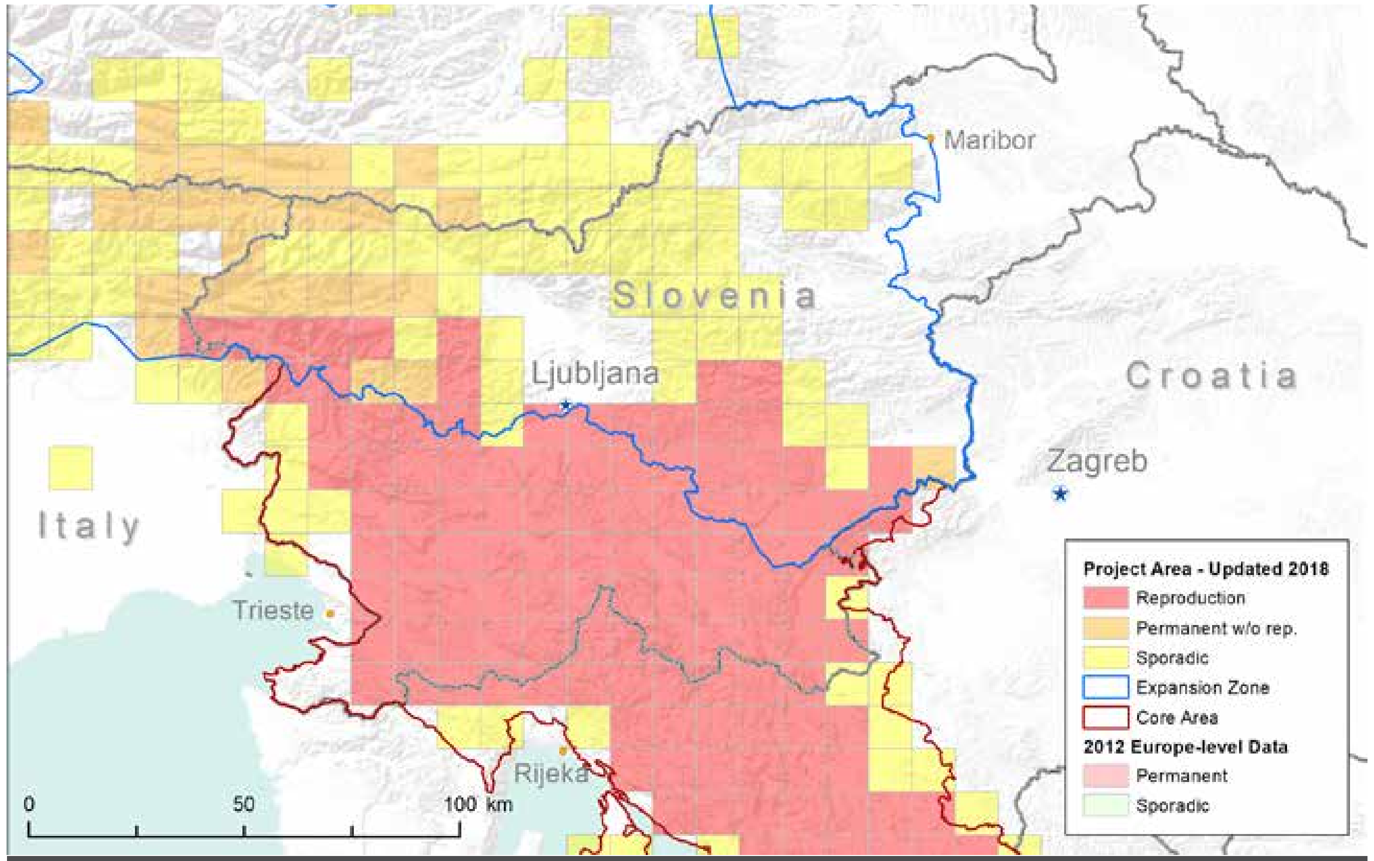
Predictive maps revealed a broad range of suitable but fragmented patches of bear habitat. The largest and most important patches for connectivity occurred in the current distribution range of the species, with the most suitable habitat lying in the pre-Alpine and Dinaric populations. Connecting viable patches to host female home-ranges is possible through stepping-stone patches of corridors reachable within the estimated dispersal distance of females. Unified transnational decision-making is required for the conservation of stepping-stone patches, facilitate bear mobility, and ultimately connect bear populations.

The brown bear in Slovenia

The central area of brown bear distribution in Slovenia is the High Karst. This is the area of dense mixed forests with rugged terrain and poor visibility (Simonič, 2003). Here local bear densities exceed 40 bears/100km2, but towards north population densities decrease towards north (Alpine region). At the border with Italy and Austria, there are very few male bears and almost no females (Jerina et al. 2013). At the beginning of the 20th century, bears were close to extinction in Slovenia with only 30-40 animals in the south of the country (Simonič, 1992). After World War II the population quickly grew and expanded its range. In 1966 a core area was established in the south of the country where 95% of population was present, about 150 animals. In 1992 brown bear population expanded even further as bears outside the core area became protected in effort to naturally recolonize Alps (Simonič, 1992). Protected status allowed bear population to substantially increase with bears living outside of the core area representing 25% of entire population (Jerina et al. 2002). Studies on sex structure of migrating Slovenian bears (Jerina et al. 2008) showed that while most of the dispersing individuals (from the core area in the south of the country) are males who frequently travel large distances, females are less inclined to travel from the area where they were born or if they do, they don't go far. Exceptions occur in expanding and dense populations where some females will exhibit long distance dispersal (Swenson et al. 1998). Researchers were able to find migrant male bears throughout Slovenia while females were rare and mostly present near the borders of the core area. Bears in the areas without females had to travel back to the core area or near it to find a female during mating season during which they have to cross different roads.

Traffic related mortality is an important factor affecting Slovenian brown bear population. It is the second cause of bear mortality with hunting being the first. In average 16 bears are killed each year on the roads or railways. Majority of the traffic collisions occurs on regional roads, followed by railway collisions and highway mortality. Data analysis showed seasonal variation in bear-vehicle collision patterns with one peak in autumn (September, October) for road collisions and two peaks for bear-railway collisions: in late spring (May, June) and autumn (September, October) (Jerina et al. 2015; Petkovšek et al. 2015). First peak occurs during the mating season when the movement activity of bears is the highest, while the second one is connected to search for food to accumulate fat reserves (Jerina et al. 2015). Traffic mortality not only directly affects the long-term viability of bear population, but also indirectly affects the gene flow and limits the dispersion of individuals. Additionally it also represents a big risk to drivers and passengers.

Highway Maribor-Ljubljana-Postojna-Razdrto-Nova Gorica divides Slovenian brown bear population into Alpine part (NW of Slovenia) with low abundance, low density and higher male sex ratio and the southern part (Dinaric part of Slovenia) with higher abundance, density and sex ratio in favour of females (Skrbinšek et al. 2008). The highway is fenced with 1.60m high wildlife fence to prevent ungulates access to the road, but it is not bear proof, so bears will often climb it (Kaczensky et al. 2003). Along Ljubljana Razdrto highway, no wildlife bridges or tunnels are available to act as safe crossing structures, however on



Bear distribution area in Slovenia (2017 data).

the highway beyond Razdrto, several wildpasses were implemented (Adamič et al. 1996, after Kaczensky et al. 2003). Traffic volume of Ljubljana-Postojna is over 48000 vehicles over day (PIC 2014). Parallel to Vrhnika-Postojna highway is an unfenced railway that connects Ljubljana to Trieste and Rijeka with trains that pass every 30 minutes (Kaczensky et al. 2003).

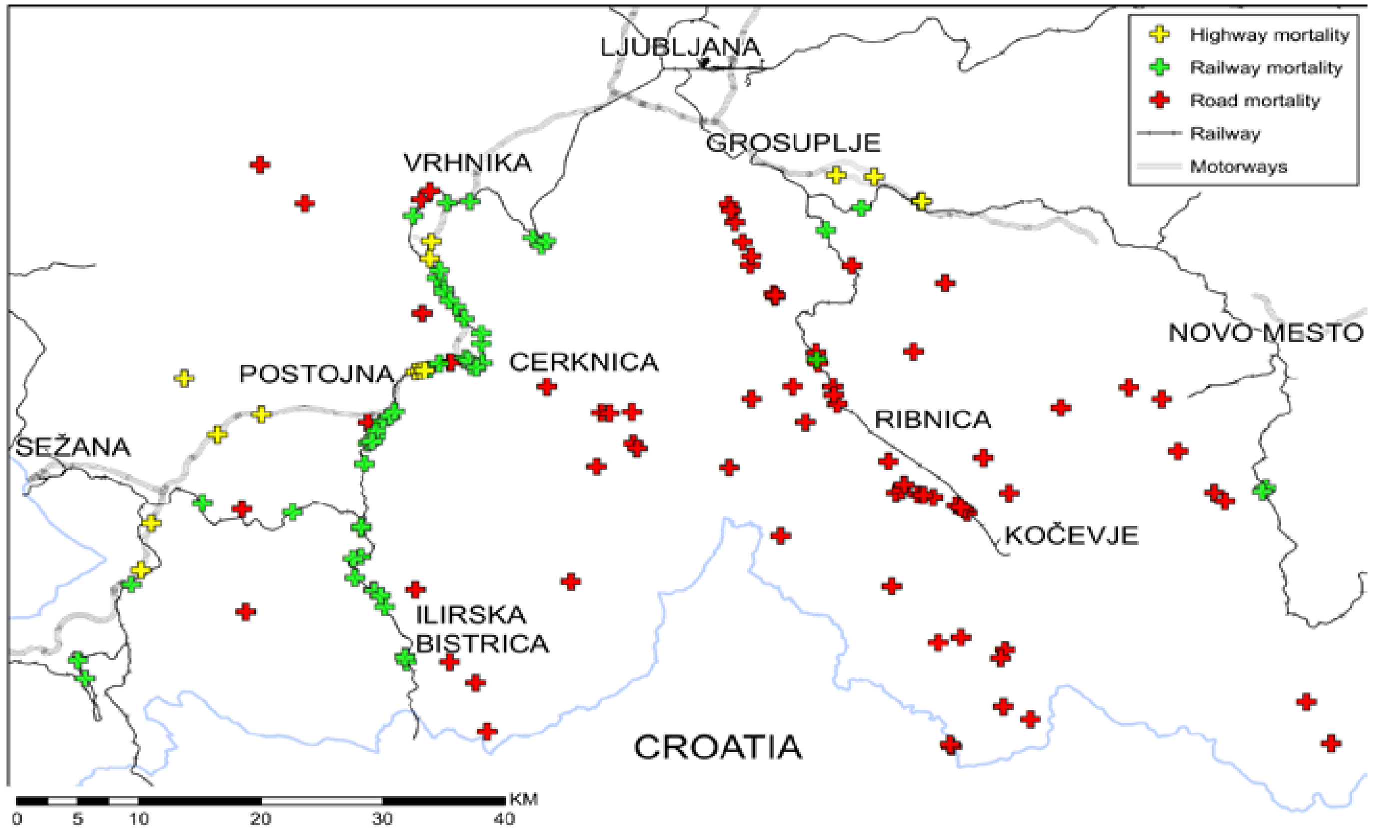
Main road Ljubljana-Kočevje also has a high number of bear-vehicle collisions (Jelenko Turinek et al. 2018). Action plan for the implementation of the mitigation measures for reducing road mortality of brown bear in Slovenia (June 2015), recognizes hotspots of bear collisions for roads and railways and suggests mitigation measures for the most problematic parts.

Study by Kaczensky et al. (2003) tracked the movements of bears living in area of Ljubljana-Razdrto highway and railway to observe how the highway influences their movement. Results showed that bears did not avoid the vicinity of the highway, but it still presented a barrier to the bears as very few bears actually crossed the highway, mostly just a few subadult males and no adult females.

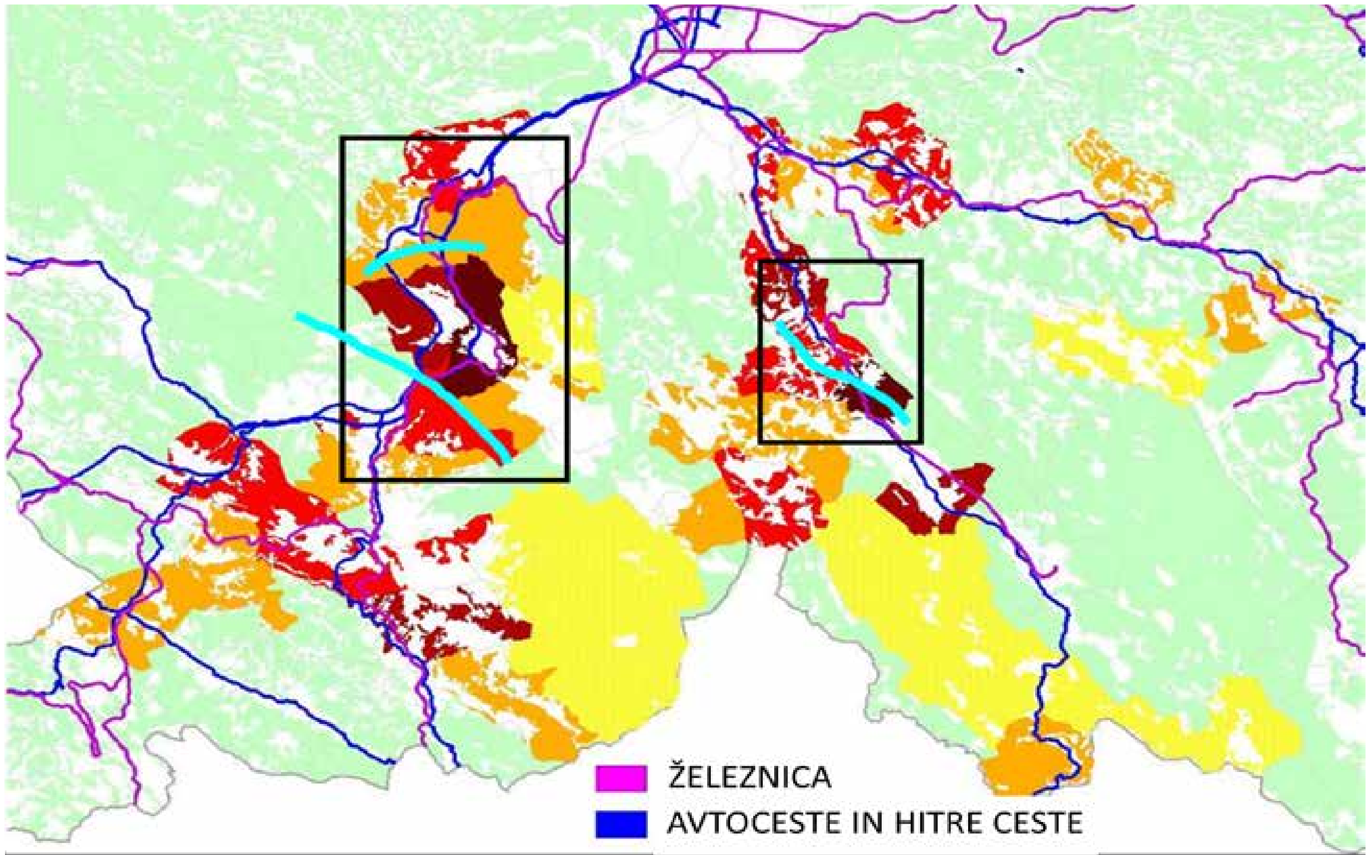
The brown bear in Croatia

The bears in Croatia, together with those in neighbouring Slovenia, are the westernmost, genetically related stable population, potentially representing the last available source for the reinforcement of bears in Western Europe. Thus, bears from Croatia, Slovenia and Bosnia and Herzegovina are genetically identical to the remaining bears from the Alps

A positive development for a better protection of bears in mountainous regions was the establishment of Forest management units in 1960, as they became responsible for bear management. Active conservation



Representation of locations in Slovenia where bears died in traffic related accidents (motorways, railways and local roads) between 2004 and 2014 (Al Sayegh Petkovšek et al. 2015a)



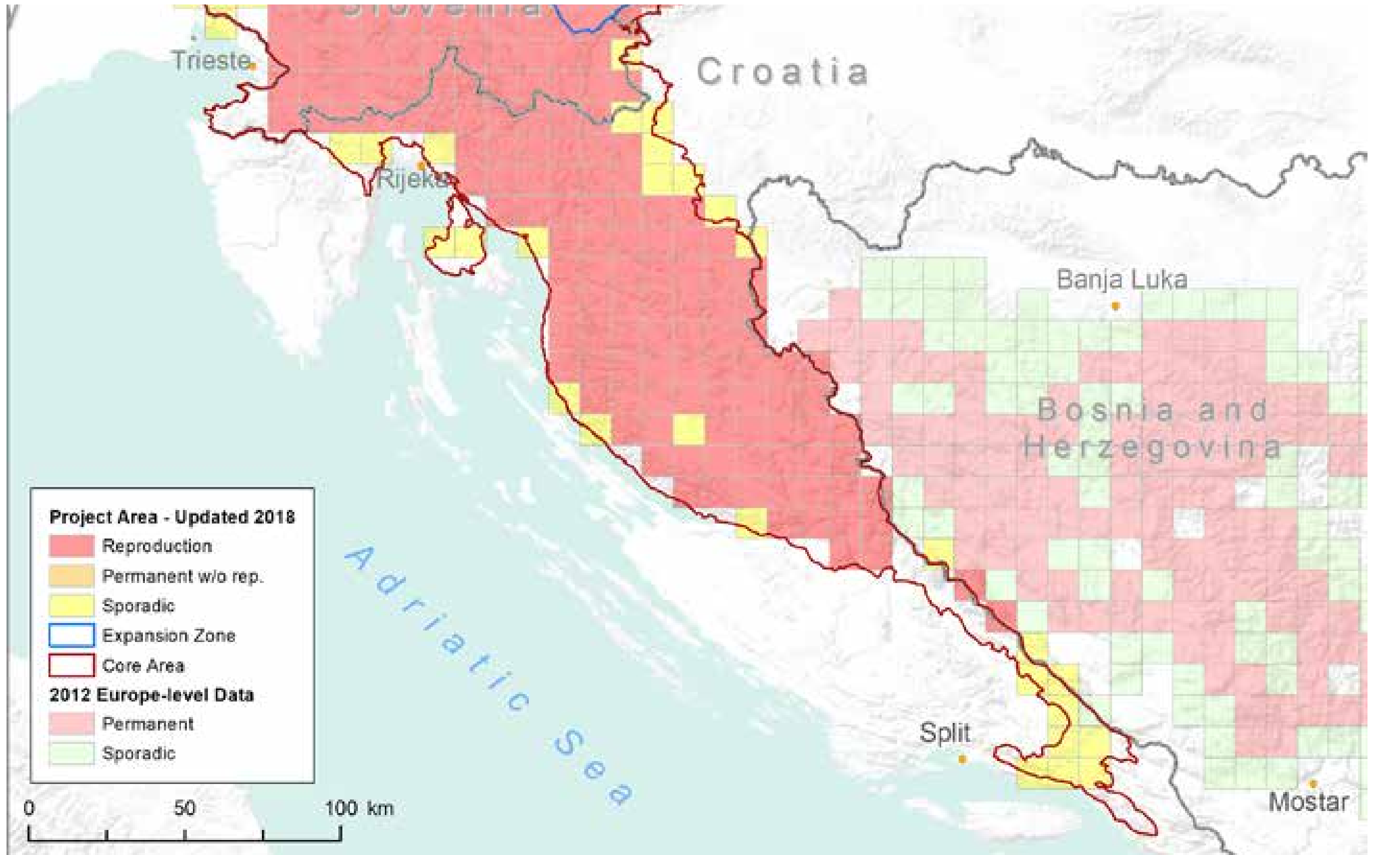
Areas/habitat patches that represent the biggest risk to bears for traffic related mortality (Jerina 2005, unpublished)

measures, such as the prevention of illegal bear hunting, selective use of poisoned baits for the reduction of the numbers of wolves and foxes (in 1973 the use of Cyonan poison was prohibited) and additional feeding of bears, soon gave the first positive results. In 1960, approximately 30 bears were present on the hunting grounds of the Delnice Forest Management Unit. In 1970 in just one of the Delnice hunting grounds (52.300 ha) 55 bears were counted (from high stands near bear feeding and reproduction sites; the number includes females with cubs). Ten years later the number of bears on the same hunting grounds had doubled. Along with the growth of the number of bears, bear harvesting activities increased as well.

The total bear distribution area in Croatia extends over 11.824 km^2. The permanent bear presence habitat extends over 9.253 km^2, while the occasional bear presence habitat extends over 2.570 km^2.The bear habitat is largely located in the high karst area. Altitudes range from 0 m (sea coast) up to 1750 m of the highest peaks of Velebit. Since the habitat is preserved to a great extent, the karst elements are present in their typical form. Bears are distributed over the entire Gorski Kotar and Lika regions, the western and southern part of the Karlovac county, the Učka and Ćićarija mountains in Istria, the central and northern part of the island of Krk, the Žumberak mountains, the coastal part from Bakar to Maslenica and the area surrounded by the Kamešnica, Mosor and Biokovo massifs.

In 1997 and 1999, attempts were made to estimate the number of bears in Croatia. On the basis of the assessments and data collected from local hunting management experts and bear biologists for different parts of the bear range, in 1997 the number of bears was estimated approximately to 378 (340 to 415). Similarly, like in Slovenia the bear population in Croatia increased in last 20 years and is estimated to 800-1000 individuals.

In Croatia there is up to 1.288 km of constructed motorways, which essentially contribute to the fragmentation of wildlife habitat. Although enclosed, highways represent just one more obstacle to the



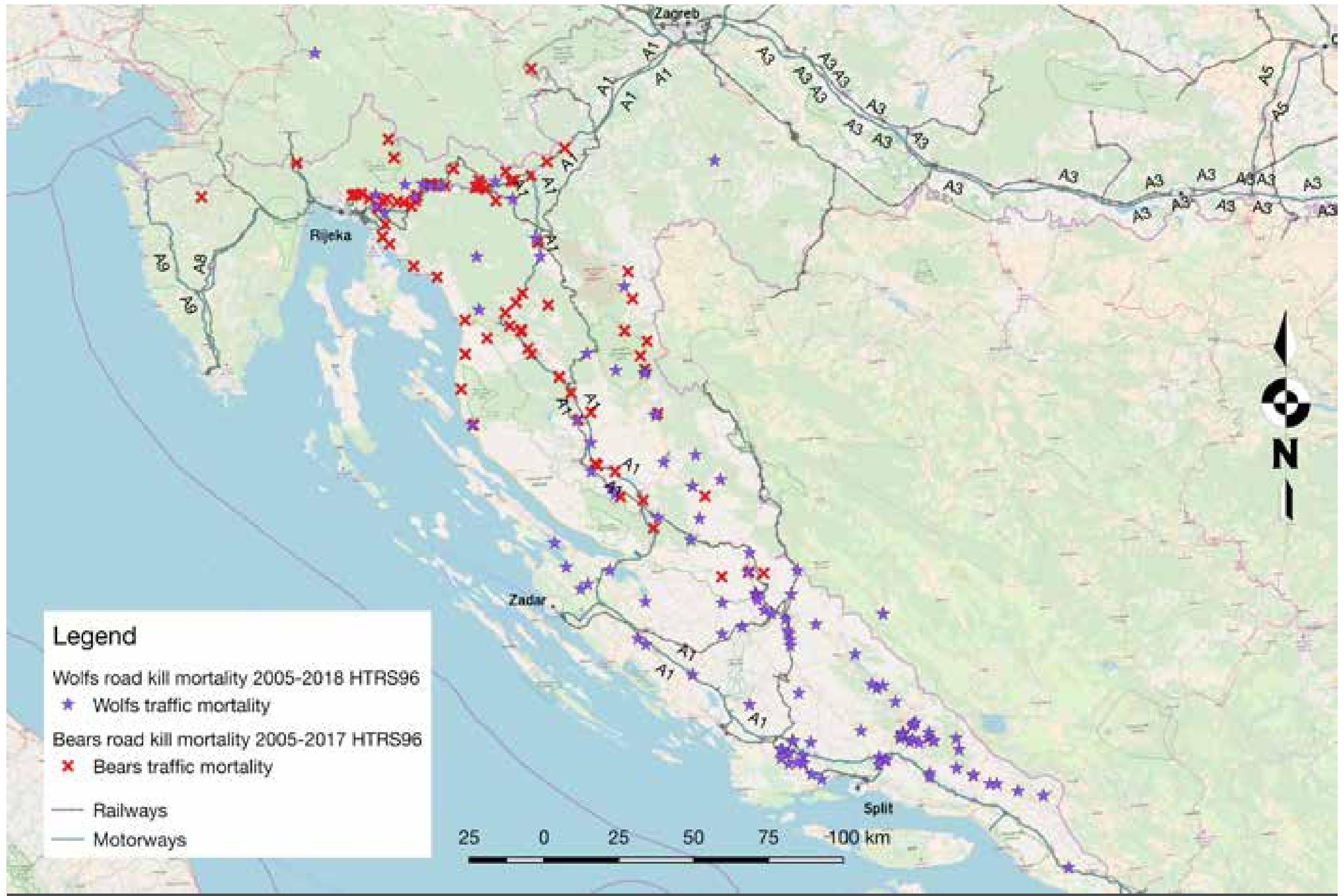
Bear distribution area in Croatia (2017 data).

natural migration of wildlife. Traffic-related mortality represents important cause of bear mortality in Croatia, too. There was 156 bears killed in vehicle collisions in the period 2005-2014. In Gorski Kotar (Rijeka-Zagreb highway) there were at least 73 killed bears by traffic during the period 1963-1995, representing 19% of the total bear mortality at that time. In later period 2005-2010 there were 92 registered vehicle collisions with bears in Croatia. The majority, 53.3% of the cases of detected bear mortality occurred on roads, 26.1%, 27.2% on highways and 46.7% on railways (Jerina et al. 2015).

Impact of transport infrastructure and traffic related mortality on bear expansion into the Alps

The corridor east of Ljubljana leads through very fragmented areas. Since a significant defragmentation with removals of settlements and reforestations on a large scale is unlikely, its functionality for the future is questionable. The corridor to the northwest, however, is well intact and connects the Dinaric Mountains directly with the Alps. Here the barrier effect of the highway Ljubljana-Nova Gorica is the biggest obstacle.

Despite previous research on bear vehicle collision in Slovenia and Croatia (Huber et al. 1998; Jerina & Krofel, 2012; Krofel et al. 2012), it has not been known until recent research within LIFE Dinalp Bear (Jerina et al. 2015) if and how vehicle collisions affect brown bear population and their expansion into the Alpine area. In addition, there have also been considerable changes in transport infrastructure since the last studies have been published (e.g. building of highways in Gorski Kotar and Lika in Croatia)



Evidence of bear and wolf mortality in traffic related accidents for Croatia between 2005 and 2017-2018 (Huber et al. 2018)

and until now no research has simultaneously analysed bear mortality at the transboundary level. In the last few years a significant amount of new data has been gathered which enabled more accurate analyses than ever before.

In comparison to other causes of mortality, younger bears and females are more susceptible for vehicle collisions. According to the absolute number of vehicle collisions in both sexes the highest number of bears killed in vehicle collisions is among cubs, and the number gradually declines with age. But this is mostly a consequence of the structure of the living population which is under strong hunting pressure and consequently only small part of young bears survives adult age (Jerina & Krofel, 2012; Krofel et al. 2012). Similarly, the increasing proportion of females among older bears killed in vehicle collisions is connected mostly with the structure of the population.

The Alpine part of the population (i.e. the area north of the Ljubljana-Nova Gorica highway) contains only a small portion of bears in Slovenia and in contrast to other areas the sex ratio in this part of the population is strongly male-biased (Skrbinšek et al. 2008). This reduces reproductive potential and consequently might make this part of the population more vulnerable to traffic-related mortality and strongly dependent on the core area population. The results have confirmed this hypothesis and have shown that without vehicle collisions this part of the population would have been demographically self-sustainable. But in the current situation the mortality rate is higher than the birth rate. Mortality is not significantly different from that in the core area, but their birth rate is significantly lower due to small number of females. This is the main reason why this area presents the population sink and is in long-term dependent on the constant influx of animals from the core area of the population. Basically the only option to increase the birth rate would be by increasing the number of females in this area, which is (in addition to managing the population south of the highway) largely connected with the improvement of the connectivity of the Alpine area with the population core in the Dinaric region. In this sense, the permeability of the Ljubljana-Nova Gorica highway/motorway likely plays a crucial role. In total, the Dinaric Mountains and the Alps provide large suitable areas for brown bears and these areas are mostly still connected. However, barriers exist already and should be mitigated for easier movements of brown bears and other wildlife species as well.

4. PLANNING

The avoidance of ecological impacts by not developing the proposed infrastructure may be the only solution to avoid fragmentation of vulnerable habitats. Adapting the alignment of the infrastructure to avoid bisecting vulnerable habitats, reducing the land take of the road corridor or reducing disturbance to adjacent habitats minimise the impact but do not entirely avoid fragmentation. Avoidance of habitat fragmentation should become the first principle applied in the planning, design, construction and maintenance phases of infrastructure as well as the upgrading or closing of existing roads and railways.

Habitat fragmentation should be minimised when planning new infrastructure or the upgrade of existing infrastructure. Carrying out Strategic Environmental Assessments (SEA) on plans and programmes and Environmental Impact Assessments (EIA) on projects ensures that environmental considerations are taken into account at an early stage. SEA and EIA should be carried out according to EU directives and their national implementations. The overall aim of the SEA and the EIA is to identify possible environmental impacts of plans and projects before a decision about implementation is made. Another aim is to ensure public consultation on the project. Before a plan or project is adopted and before any construction begins, all SEA and EIA are subject to a public hearing. At this stage, relevant authorities, stakeholders, NGOs and the general public can comment on the plans and influence the project before a final decision on implementation is made. As some degree of fragmentation is inevitable when building a road or railway, mitigation measures must be taken into consideration to ensure permeability of the infrastructure in dispersal corridors and priority habitat areas. In situations where infrastructure crosses especially vulnerable areas or where mitigation measures are inadequate or impossible, compensatory measures may be necessary.

Fragmentation issues relating to existing infrastructure are somewhat different. For a large part of the existing infrastructure, mitigation measures may not have been taken into consideration during planning and design. In these situations, the fragmentation brought about by the existing infrastructure may have already affected the area, and other sources of fragmentation, unforeseen at the time of the study, may have appeared. New evaluation may be necessary if the assessments that were originally made are outdated.

Strategic environment assessment and Enrvironmental impact assessment

All new regional plans and programmes in the EU countries and other European countries are proposed to be subject to a SEA, according to Directive 2001/42/EC of the European Parliament and of the Council of 27th June 2001. The deadline for the implementation of national legislation was 21st July 2004. The SEA ensures that environmental considerations are taken into account in the development of large-scale planning policies. The SEA should comprise a general description of the plan or program itself, its main objectives and its relation to other relevant plans and programs. The SEA process integrates environmental considerations in the decision- making process prior to project-level EIA.

All major projects, including infrastructure projects, are subject to EIA according to the EU Council Directive (97/11/EC of 3 March 1997). An EIA relates to a specific project. The process ensures a detailed assessment of adverse and beneficial environmental effects for a range of alternative solutions, depending on the detail of assessments included in the SEA process, which varies between countries. These assessments are followed by recommendations for measures to minimise or compensate negative environmental impacts. All environmental factors are also assessed for the situation where the project or the plan is not implemented. This is often termed the "do nothing" scenario. The future situation without the project should be described primarily for getting a reference. The EIA is used as a basic document throughout the project planning and design phases and as a common reference and communication tool.

Spatial scope of assessments

Clearly defining the study area and analyses is crucial for a meaningful study of fragmentation issues. In general, the study area must be much broader than the corridor within which the project is to be located, and is determined by the existing landscape structures, fragments and features, which are sources of fragmentation. In defining the study area, different scales should be considered:

- **National scale:** The significance of the wider area surrounding the proposed construction is assessed considering the nationwide occurrence and migration behaviour of each species. From this point of view, areas connecting isolated populations are considered crucial; these locations may be vital to the continuing existence of a population even when the particular species does not live permanently in the area. A further priority are locations where a line barrier would divide a population in the area of its population nucleus: observation of long distance migration routes, local bottlenecks and the connection of isolated populations - even when the target species does not permanently live in the area. 1:250000 may be an appropriate scale.
- **Regional scale:** focussing on the impact of the infrastructure, other barriers in the area, topographical connectivity, wooden areas, etc. An important objective is to describe the frequency and location of mitigation measures. 1:50000 may be an appropriate scale.
- **Local scale:** detailed studies of the area including populations, habitats and their locations. Useful information includes observations from local specialists, hunters, forestry personnel, etc. An important objective is to describe the exact frequency, location and dimensions of mitigation measures. 1:5-10000 may be an appropriate scale.

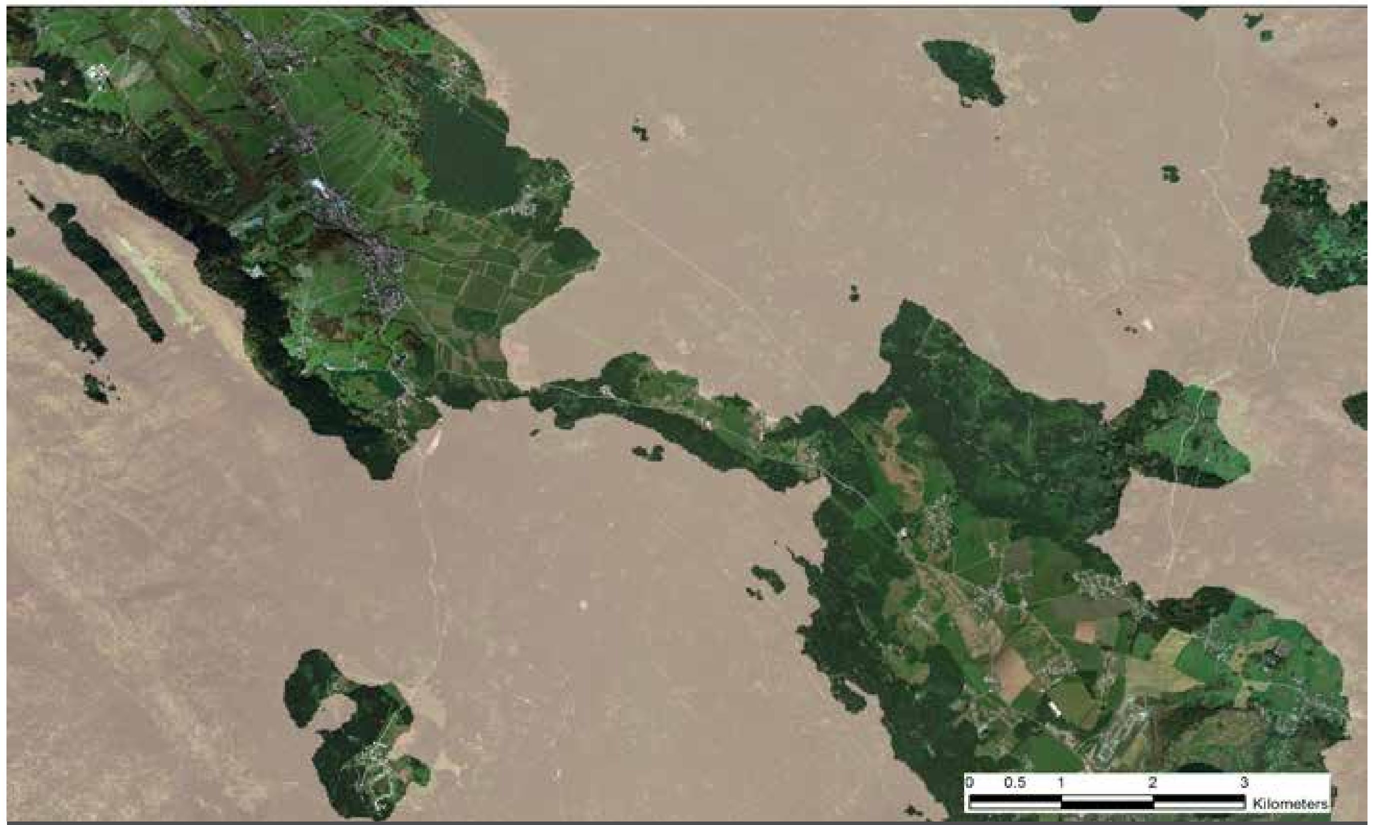
Mapping should include conflict points with migration routes, possible negative influences on vulnerable areas, fragmentation of valuable habitats, etc.

Using the bear habitat suitability models and potential corridors in EIA and mitigations of existing infrastructure

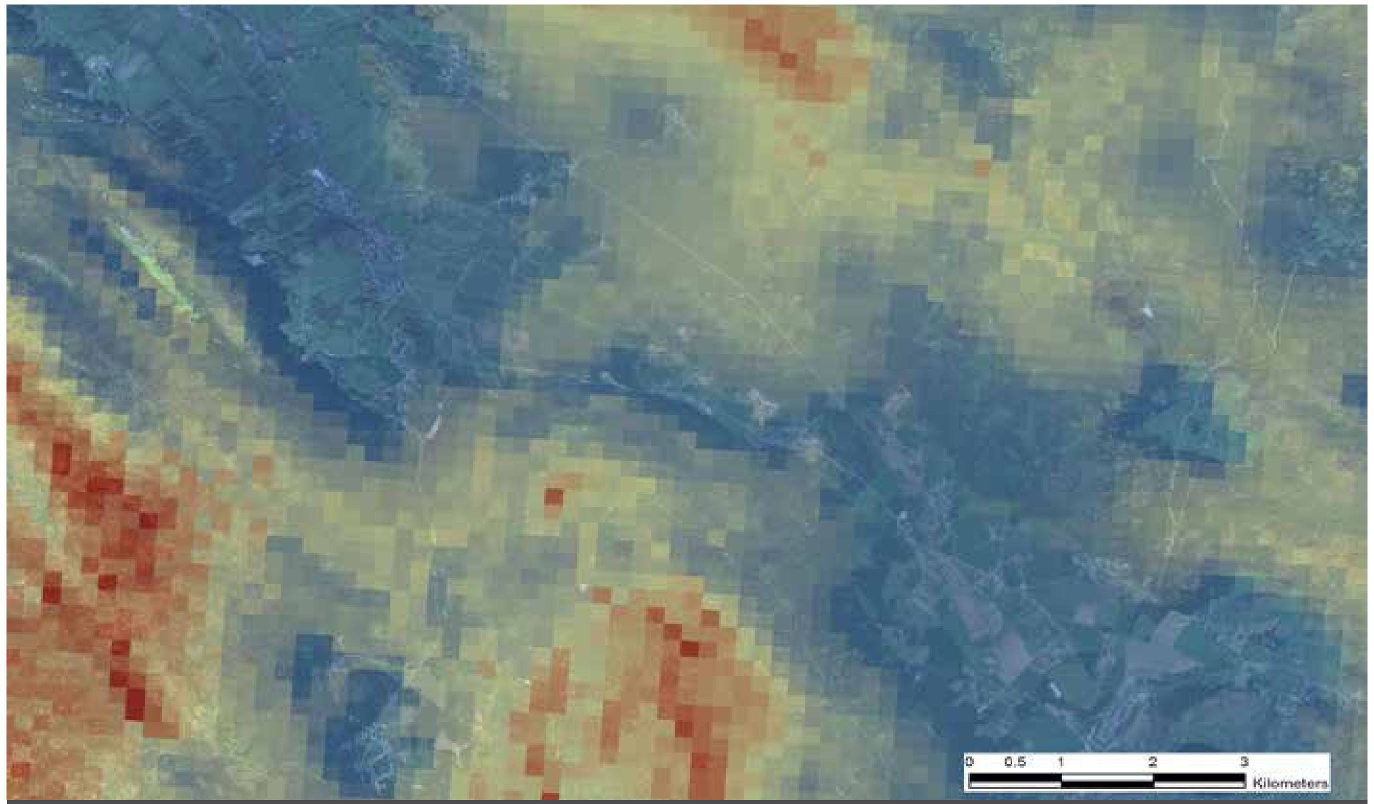
For the purpose of more objective decision-making in the assessment process, the entire area of central and eastern Alps and Dinaric mountains (that is Slovenia, Croatia, southern and central part of Austria and NE part of Italy) has been included in the (Rodrigues Recio et al. 2018): (i.) bear spatial explicit habitat suitability model, that comes in two forms: 1.a) continuous habitat suitability model shows bear habitat suitability on the scale from 0 (the worse one) to 1 (the best one) and 1.b) discrete habitat suitability model that defines areas that are suitable and unsuitable for bears. Both models can be useful for the assessments, since the first one (continuous) provides detailed information and indicates the most probable passages between larger habitats and the suitability of individual habitat patches (higher value alongside the entire patch means that the patch is more suitable), and the discrete model is more transparent), (ii.) Models of importance of habitat patches for joint connectivity of the Alpine-Dinaric bear population. This model includes habitat patches that are more important for connectivity at the level of population and within population (iii.) Line models of potential corridors that connect internal parts of corridors inside the same habitat patch and between the patches. Potential corridor models that connect patches and parts of patches are marked with lines (line objects). When interpreting the model, a critical approach should be applied since the scale that was used does not provide for exact definition of corridors. In general, we tried to apply a conservative approach and sometimes the corridors are marked even if they might not really be functioning, and most of all, the locations of corridors might be very approximate. When the borders of two habitat patches are parallel, (there is a rather equally wide belt of a non-habitat or a matrix), these two patches can be connected with numerous potential corridors and it is not possible to foresee the exact location of this corridor. In such cases, it is necessary to implement a detailed assessment and include an expert on animal ecology and assessments.

All modes show which areas are suitable due to their natural characteristics and thus a bear could live in them; however, it is not necessary a bear has been present there already (or which corridors shall be important in the future). The bear population in Slovenia, Croatia and Italy is extending and will probably continue to do so in the future, therefore the assessments and developments should consider the habitats and corridors that are currently not inhabited by bears or that function as corridors, since they could be inhabited or could function as corridors in the near future. As it has been mentioned before, the locations of corridors marked in the models are only approximate. A more detailed assessment should be carried out in those parts where the habitat patches are relatively close to each other and the bears could be passing between them, and/or in the parts marked as corridors (the red areas) and experts for carnivores should be included and carry out a more detailed assessment.

Aerial photograph of the crossing „Jasnica" that connects eastern and western complexes of the bear habitat in Kočevje. A hypothetical development is located exactly on the crossing (violet circle) (Jerina 2019).

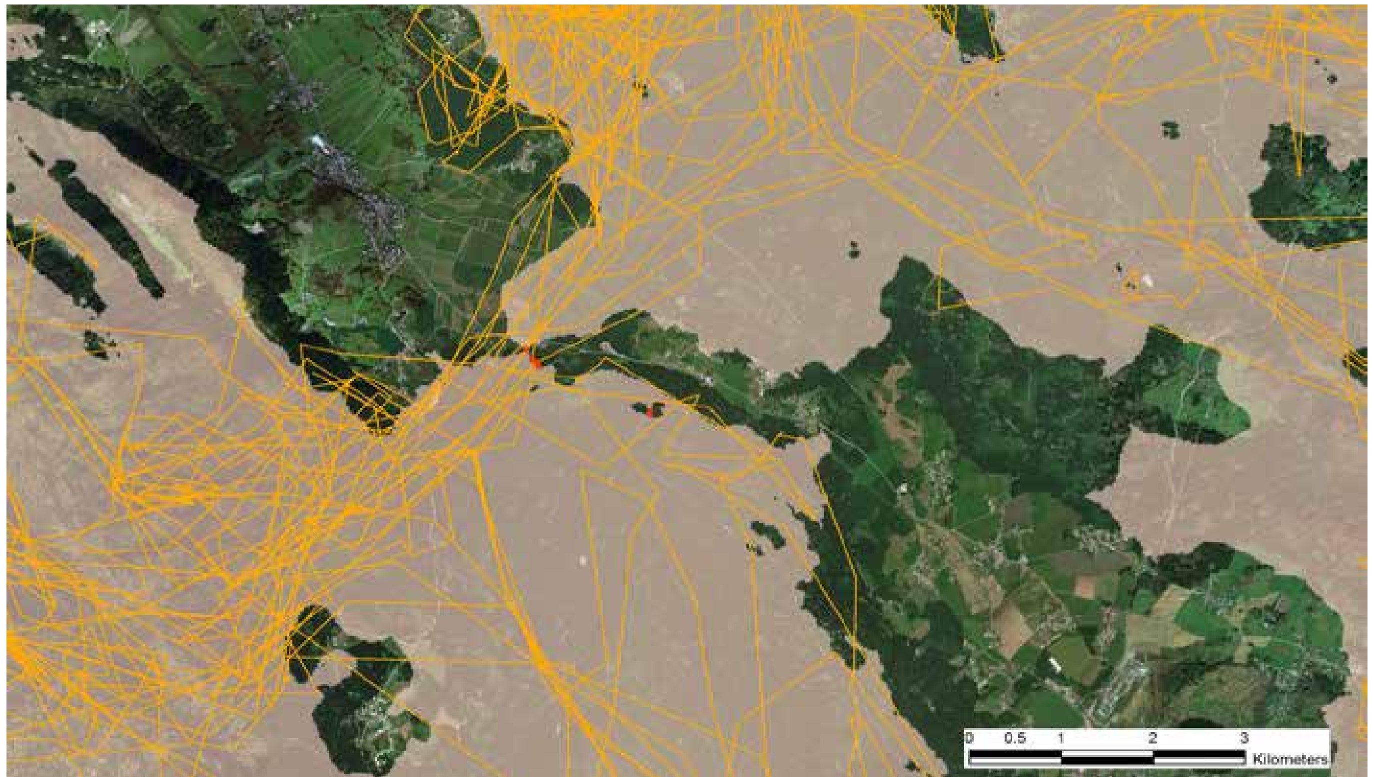


Habitat suitability of the site in the area of the assessed development: discrete model. The brown translucent colour marks the areas that are suitable for bears and the rest of the areas are considered not suitable (the uncoloured ones) (Jerina 2019).



Habitat suitability of a site in the area of the assessed development: integrated model. Habitat suitability of the site is shown with a colour gradient from the lowest (0 marked in green) to the highest (1 marked in red). The model differs from the one in Picture 2 because it provides more detail and information, but on the other hand it is less transparent (Jerina 2019).

The model of importance of habitat patches for connectivity at the level of population and between populations (the brown areas) and the model of corridors inside populations (red lines). From the point of view of global connectivity, the entire habitat complex east and west from Jasnica is important, and this means it forms only one patch (part of the same area with high importance - the same colour is thus used), and this area is internally connected in the area of Jasnica (red lines) (Jerina 2019).



The identified crossings and movement paths of some of the bears that were monitored in the specified area with the use of GPS telemetry (Jerina et al. 2018). The picture feature movement paths of the monitored bears that are market in orange. This picture already shows that the location of the corridors (red) is just an approximate one, considering the actual crossings. The passage in this concrete example is wider that shown in the model (Jerina 2019).

Planning process

Literature suggests first finding key habitat linkages using GIS program or zones important for wildlife connectivity after which future planned projects should have been taken into consideration to decide for best crossing locations. There are different resources that can be used for this purpose: aerial photographs, landcover vegetation maps, topographic maps, wildlife movement data, road kill data and road network data (Green bridges, review). The COST European handbook (Iuell et al. 2003) advises to consider landscape, habitats and target species and to evaluate the importance of importance of habitats and species at local, regional, national and international level when selecting the wildlife crossing type. It further emphasizes the importance of bridge connectivity to its surroundings. As the lifespan of such structures is around 70-80 years, its location and design need to account for changing dynamics of habitat, climate and wildlife over time (Clevenger and Huijser, 2011). In order to determine if crossing structure will be cost effective, the price of a structure must be weighed against several variables, including the frequency of collisions in a given location, the cost of structure and associated fencing, the expected lifetime of the structure, the maintenance costs of roadways with versus without the structure, and the estimated effectiveness of the structure in preventing collisions (Wildlife passage engineering design guidelines, 2010). Due to their high cost, bridges and overpasses should always be built with more than just target species in mind. Data suggests that hares, badgers and foxes prefer to walk on gravel areas. Planning process should be a collaboration between engineers and biologists.

During the planning process multiple planning parameters are dealt with at the same time and the proposed solution is often a result of several functional, economic and environmental factors. It can be very difficult to isolate the costs that are related to fragmentation issues. Often benefits could increase over time when new infrastructure has secondary effects on urbanisation or other land-use change which increase pressure on habitat fragmentation. The calculation of benefits should therefore take into account the long-term efficacy of avoidance and mitigation measures.

Longevity of avoidance, mitigation and compensation measures is crucial. Solid, persistent solutions and engineering constructions with a long life span are highly recommended. Wildlife can be very sensitive to temporary disturbance from the renovation of mitigation measures, which could increase the fragmentation effect.

Large animals only use underpasses, overpasses and landscape bridges (=green bridges/ecoducts).

Wildlife passage engineering design guidelines (2010) included a list of crossing preferences for large mammals. Crossing structures should be large, open with a clear line of sight to the other side and as flat as possible as steep grades will reduce the openness. Grounds on either side of the crossing should be dry and natural substrate (soil, vegetation) should be used. Vegetation on the crossing structure should be similar to that on both edges, however density of vegetation should be planned according to the target species.

The assessment must be followed by recommendations of which locations and sections to improve to reduce the barrier effect. The recommendations will typically include modifications to existing tunnels, installation of new or additional tunnels and plantings and changes in maintenance practices.

Establishing passages across existing barriers is much more expensive than building passages during the construction of new roads and railways. For a large part of the existing infrastructure, bridges, culverts and other constructions can be adapted to provide mitigation measures. By making small adjustments, existing human passages may also be suitable for adaptation to joint-use passages.

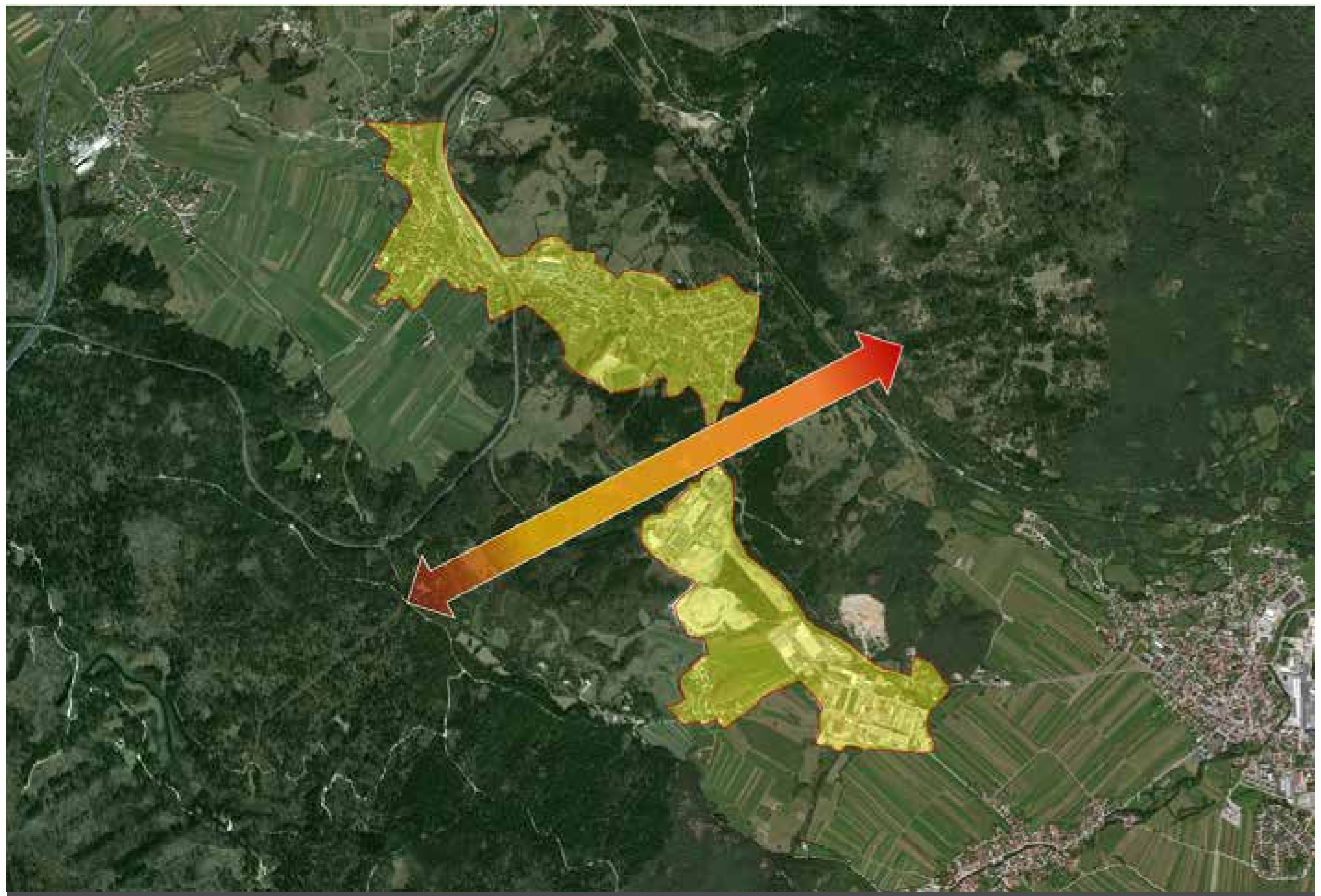
Upgrading infrastructure often increases the barrier effect. If existing infrastructure is not already built with mitigation measures, construction works provide an excellent opportunity to incorporate new measures. Establishing passages across existing barriers is generally much more expensive than building passages across new roads and railways.

Environmental studies that were originally made may be outdated and a new evaluation is often necessary: the fragmentation brought about by the infrastructure could have already affected the area and other sources of fragmentation, unforeseen at the time of the study, could have appeared. Therefore additional analyses and discussions about the possible effects of the route should be re-evaluated. The sensitivity of the habitats with respect to fragmentation, the mobility of the animals, the size of their home ranges and how sensitive they are to disturbance, are all factors to be considered.

5. WILDLIFE CROSSINGS

In most mammal populations, under normal conditions, there is always a part of the population that does not maintain permanent home ranges and moves over large distances. These are frequently adolescent individuals pushed away from their natal/parental home areas; in other cases, older full-grown individuals migrate for food, sexual mates or to breed. For many species, the motivation and principles of this migration have not been entirely clarified as yet, however, it is certain that these migrations are crucial for the survival and vitality of the population. Migrations from prosperous parts of the population make it possible to permanently populate less suitable habitats, where an isolated population would become extinct within a short time. Migration makes it possible to compensate for fluctuations in numbers caused by a temporary worsening of habitat, epidemics, natural disasters, etc. On the other hand, migration makes it possible to discover new habitats and those areas temporarily suitable. Immigration and emigration within an existing habitat also provides the necessary genetic exchange to ensure that the variability of the genetic pool is maintained.

To mitigate the negative barrier effects of roads and other infrastructures, crossing structures are implemented to allow for animal movements along the major traffic pathways. When the need to mitigate against fragmentation effects leads to the construction of eco-ducts and other wildlife



An example of a habitat corridor in the industrial zone Podskrajnik that connects adjacent habitat patches suitable for bears. The area is also important for the connectivity of habitat for other large carnivores. The inadequate spread of urban areas or the industrial zone could completely disrupt such a connection. (Atlas okolja 2018) passages, the investment required can be quite substantial. If these solutions are also required on existing roads, project execution may not be simple and many agencies have found it very difficult to mobilize the resources needed. This underlines the importance of avoiding fragmentation in the first place, leaving existing habitats intact as far as possible, or contributing to their restoration. Infrastructure authorities and agencies need to maintain close contact with the local authorities and each other to ensure that purposely preserved habitats are kept intact and that the efficacy of wildlife passages is not diminished by other structures or landuse developments.

Different terms are used around the world to represent the same structures. In the USA crossing structures are divided into four types: landscape bridge, wildlife overpass, multi-use overpass and canopy overpass, in Europe the term landscape bridge is mostly used in reference to green bridges and ecoducts. Differentiating in size, all are designed exclusively for wildlife use, with the exception of multi-use overpasses which are designed for human and wildlife use. Most of the wildlife overpasses built in Europe varies from 25-80m., while bridges are over 100m long with recommended minimal width of at least 70m.

Choosing the type of crossing depends on target species, length of the crossing and topographical features. For large mammals, crossings should be located near the paths traditionally used by them.

Ideally, crossings for wildlife should have limited access for people to ensure maximum use by wildlife. (Foto: Kusak J.)

Paths can be determined with help of fieldwork (mapping tracks), road kill statistics or by consulting with locals/hunters. Ideally, all crossings designed for wildlife should have limited human access to ensure maximal use by wildlife. While it is best if structures are made specifically and exclusively for animals, in urban environment where natural land is limited, human use is inevitable for recreational and transportation purposes. Often existing structures can be adapted to suit the demands of animals and serve as fauna passages.

Frequency or density of crossing passages

As one crossing structure along the motorway is not enough, more structures should be planned. To determine the frequency of crossing sites, different elements should be considered: species of animals, size and connectivity of the habitat, size of target populations and other anthropogenic structures along the motorway.

The density of fauna passages required to effectively maintain habitat connectivity is a major decision in planning mitigation measures. Deciding on the number and the type of measures required will depend on the target species and the distribution of the habitat types in the area. In some cases one or more wide passages will be appropriate whereas other problems will be better tackled by a larger number of smaller scale measures. An additional argument for constructing several passages is to spread the risk in case a passage is not used as predicted. In order to determine the number of passages required, the behaviour of target species can be used as a guiding factor. The catchment area of fauna passages is limited even for mobile species. For larger animals, individual home ranges and social interaction between individuals limit the range from which animals will be able to use a passage.

When determining the frequency of passages, all opportunities for animals to cross an infrastructure have to be considered, including the ones that may already be available. In general, the density of passages should be higher in natural areas, e.g. forests, wetlands and in areas with extensive agriculture, than in densely built-up or intensively-used agricultural areas.

Distance between two crossings should not be longer than the average daily movement of certain species. For Croatian brown bears that is 1.4 km (Huber and Roth, 1993, cited by EuroNatur, 2010), while it is 2.2 km for wolves in Dalmatia (Kusak et al. 2009, cited by EuroNatur, 2010). Another option requires at least two crossing structures within individuals' home range.

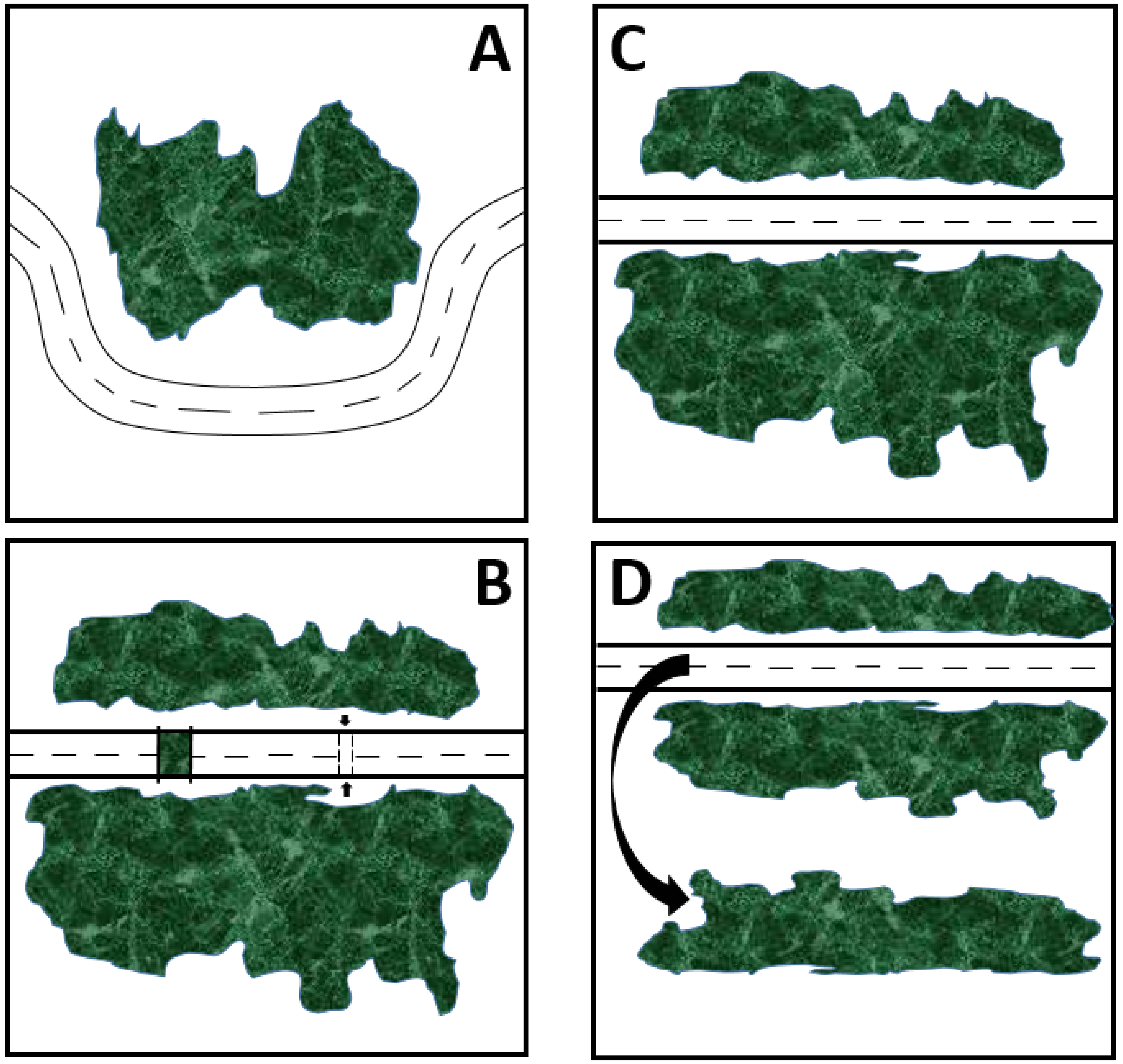
Passages and other connectivity mitigation structures

The best mitigation involves the selection of the least damaging route alignment combined with sensitive scheme design. The underlying principles are avoidance of damage or direct effects or, if this cannot be achieved, mitigation of impacts. Where impacts cannot be fully mitigated compensation may be necessary.

Existing infrastructure

The construction of new infrastructure and in most cases the upgrading of existing infrastructure requires the consequences of habitat fragmentation to be taken into consideration, for example through the EIA. In contrast, there are no direct legislative rules to ensure that barrier problems in relation to existing infrastructure are solved.

Nevertheless, through the Habitat Directive (1992), EU member states are obliged to "establish supervision of unintentional catch and killing of species mentioned in annex IV". This includes traffic casualties and the Directive is therefore relevant to existing roads. The annex states that for those species where unintentional killing is known to have a negative effect, preservation measures must be taken. It is important to identify points or sections where the existing road conflicts with natural structures (rivers, river valleys, forests, etc.) that are part of the main dispersal network or are locally important habitats or dispersal areas. Furthermore, the aim is to point out where and how to improve existing measures and where it is necessary to establish new measures to compensate for the negative consequences of the road.



Schematic representation of effects and use of different ways of preventing and mitigation measures to minimize fragmentation of habitats. A – avoiding, B – fragmentation of habitat, C – mitigation measures in fragmented habitat, D – compensation for habitat loss.

Overpasses and bridges

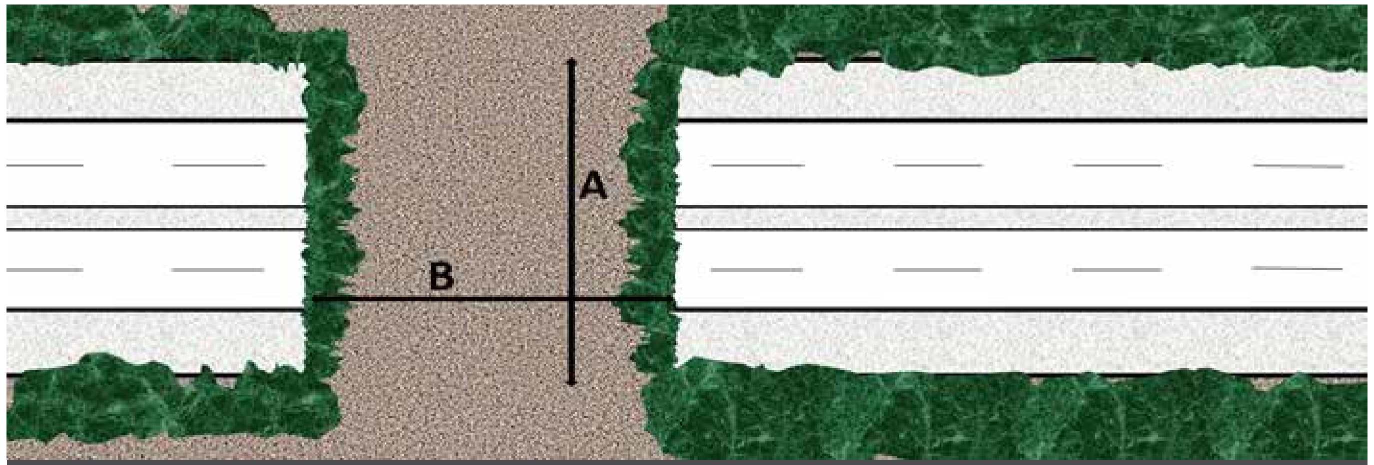
The effectiveness of wildlife overpass is proportional to their width. Generally most European overpasses are between 25 to 80 m wide with a soil layer between 0.5 to 2m deep which allows growth of vegetation. Artificial screens or earth embankments are also used to decrease the level of noise and to reduce the light from the road. Fences are placed to guide animals to the entrance (EuroNatur, 2010).

Wildlife overpasses and landscape/green bridges are purpose-built bridges, usually over a railway or road with several lanes and/or high density and fast driving traffic. They are costly but effective means for minimizing (at least locally) the fragmentation effect of road infrastructure.

Width, design and vegetation depend largely on target species. For large mammals the width and location of an overpass are more critical than the design details, substrate or vegetation. Being costly, overpasses should not be built for just one or two target species. Large mammals require wider overpasses. Standard with at least 60 m (between fences) is recommended (Bank et al. 2002). Width should increase with the length of an overpass. The minimum width to length ratio should be greater than 0.8. For narrower overpasses, screening may be needed to reduce the noise and light disturbance.

The recommended width for landscape bridges is >80m. For large carnivores the width of green bridges between 100 and 200 m is recommended to achieve full ecological functioning of the structure. The optimum width depends on the diversity and conservation importance of the habitats that have to be connected. In areas of high importance a landscape bridge may need to be several hundred meters wide to preserve the connectivity of the landscape.

Adequately placed green bridges are the most effective crossing structures to mitigate fragmentation effects in large mammal habitats, especially for large carnivores. (Huber Đ.)



Definition of measures for crossing structures: A – length of crossing structure (e.g. green bridge) and B- width of crossing structure.

When designing an overpass, arched designs should be avoided. Wildlife appear to be more hesitant to use arched structures because they cannot see across to the other side (Schrag 2003, cit. po Chisholm et al. 2010). A gradual approach should be used, ideally a 5:1 slope, to allow animals to see across to the opposite side (Huijser et al. 2008, cit. after Chisholm et al. 2010). If animal can see good habitat on the opposite side it will be more likely to use the structure.

Vegetation on the green bridge serves as a guide across it and should reflect the habitats on both sides of the infrastructure. Hedge like vegetation serves as guide line, cover, protection from light and noise from the road for larger mammal species. Only plant species native to the area should be used. Roots or trees can create maintenance problems so the choice of suitable tree species should take maintenance and traffic safety into account. Depending on the type of vegetation, soil depth can be varied. Recommendations for soil depths: 0.3m for grass/herbs, 0.6m for bushes/shrubs and 1.5m for trees. Other additional structures may be used to guide animals to an appropriate passage, either screens (solid walls) or fences. Fences are essential on the outer edge of an overpass and need a tight connection to a fence alongside the infrastructure.

Infrastructure is developed for a period of 50 to 100 years or more. Safeguarding a corridor which allows access to the overpass has to follow a similar time frame and should be part of spatial planning at local and regional scales. A proper maintenance plan should be developed. No development (housing, local roads, industrial area) should be permitted that reduces the functioning of the overpass. Hunting should be forbidden on the overpass and in its surroundings. The use of an overpass by vehicles or walkers have to be planned carefully. Preferably a narrow path should be provided for walkers to concentrate their movements.

Green bridge Osmakovec (Croatia) right after construction (2005) and after planting and natural vegetation recovery (2016). (Foto: Kusak J.)

The responsibility for maintenance has to be organized during the planning phase. People responsible for maintenance have to be properly instructed and when not involved in the planning process, a close collaboration with people responsible for road maintenance is required.

Regular inspection of the structure and the seal and draining system is essential and should be part of ordinary structure maintenance procedure. Vegetation should be maintained according to the original targets of the overpass.

Example of inappropriate construction of green bridge (Vranovića ograda, Croatia) where local road has been constructed over the bridge to connect village across highway. Separate road overpass should be constructed instead.

Multi-use overpasses

Ideally all crossings designed for wildlife should have limited human access to ensure maximal use by wildlife. However in urban environment where natural land is limited, human use is inevitable for recreational and transportation purposes. Suggestions on making a corridor or crossing useable for both people and wildlife: (1) limit access to the crossing for domestic animals and livestock; (2) human path should be on one side of the corridor, not in the center; (3) vegetation, rock and other material should be used to create a visual barrier between human part of the corridor and wildlife part as well as create overhead cover for animals; (4) shared overpasses are only recommended when the passage is wide enough and not too long.

Underpasses

Underpass for wildlife include all types of fauna passage built as a connection under the level of traffic. They are a suitable solution particularly in hilly areas or where the infrastructure is built on an embankment.

Example of multi-use overpass at Veliki Gaber (motorway Ljubljana – Zagreb), where local roads and dirt roads have been built over the pass. After the construction new housing infrastructure has been built which additionally decreased the suitability of the overpass for large mammals. (Atlas okolja)

Underpasses for large animals are primarily constructed for mammals (wild boar, deer and large carnivores). However smaller mammals readily use these underpasses as well. To ensure usage, they should be located along the paths traditionally used by the target species, where local topography channels movements towards the passage. The dimension of an underpass is defined by height, width and length. The length basically corresponds to the width of the road or railway track and is therefore fixed. For a description of the dimensions of an underpass an index of relative openness is often calculated, defined as width x height / length. While length of the underpass is fixed, width and height can be chosen according to the requirements of animals. Minimum width and height are recommended at 15 and 3-4m. The index of relative openness should be above 1.5 when underpass is planned for larger mammal use (EuroNatur, 2010). Experience indicates that mammals may learn to use underpasses situated in their home ranges. Inexperienced animals, in particular young animals in the dispersal phase or animals that use the underpasses only infrequently during seasonal migration may be more sensitive to dimensions. Due to the lack of light and water, vegetation will often not grow, but should be always encouraged. Ground inside should be covered with soil (ie. natural). Bushes planted at the entrance can act as a guide towards and through the passage. Fences can also be used for that reason. Other preferences of large terrestrial animals include clear line of sight through the structure, flat crossing structures, dry natural grounds (soil or vegetation) on either side of the crossing (Chisholm et al. 2010).

As with overpasses, underpasses should not be used for hunting purposes. Maintenance has to be organized during the planning phase and when responsible party were not involved in the planning process, close collaboration with people responsible for road maintenance is required. Regular inspections of the structure/object should be carried out and waste accumulating under the passage should be removed. Drainage should keep the interior of the underpass dry even after a heavy rain.

In addition to the location, the permeability of underpasses for large mammals also depends on the width, height and length of the structure, defined as openness index. Left: A lower openness index is unsuitable for the passage of certain types of large mammals. (Črtalič J.) Right: Underpass, under which a stream flows, is located on the edge of the underpass. (Potočnik H.)

Important part of maintenance is ensuring that all paths to and under/over crossing structures remain open and uncluttered. Any material (construction, trash…) that has been left at the site, needs to be removed as soon as possible as they affect wildlife. Often adding barriers to limit human access (large rocks) can help. (Potočnik H.).

Viaducts and river crossings

Infrastructure can be carried across valleys on embankments or viaducts. Viaducts have environmental advantages subject to the choice of the appropriate crossing point.

Viaducts are mostly suited to narrow, steep-sided valleys as they maintain connectivity for species movement and minimise landtake and fragmentation within a valley by allowing watercourses and any existing nature conservation interest to continue under the structure. Embankments are suited more for wide, shallow valleys as they can maintain some degree of connectivity through the use of appropriately sited and dimensioned culverts and underpasses.

A low viaduct is ecologically preferable alternative to an embankment and provides better links and is suitable for a wider range of species than a small underpass. It has a lesser effect on the microclimate in the vicinity than an embankment. They are particularly recommended when a watercourse has to be crossed.

Low viaducts like in Unec (Črtalič J) (SLO) and Baštica (Huber Đ) (CRO) are much more suitable for animals than embankments.

To make it suitable as wildlife crossing, surface areas beneath the viaduct should be kept or designed to be as natural as possible. Earth grounds are always better than gravel, stones or tarmac. To encourage vegetation cover, viaduct should have a minimum height of 5m (10m for wooded areas) and to provide extra light, wide roads can be separated on two parallel structures. However narrow gaps between lanes should be avoided, as they lead to sudden bursts of noise from passing vehicles. When crossing rivers, the width of the viaduct should allow at least 10m on either side to allow the growth of river bank vegetation and watercourse should be kept in natural state. If there are roads under the viaduct with night traffic, they should be screened off, to reduce the light impact. Area under the viaduct should not act as a storage for equipment, agricultural machinery or be fenced off to block access for wildlife. Placing large rocks can help to avoid the problem.

Under viaducts, natural vegetation can remain and thus links the vegetation lines on both sides of the roads, which often directs and facilitates the passage of animals (viaduct Selo). (Potočnik H.)

Tunnels provide best solution when planned infrastructure would go through an area of large conservation value. (Huber Đ.)

Area above the tunnel remains completely preserved which is especially important when it has an important ecological role, like connecting habitat patches. (tunnel Plasina, CRO

Tunnels

A tunnel may be the best design solution to protect high-value landscapes. Though construction costs may be high the benefits to the natural environment will be incalculable. The scale of these benefits is dependent upon the method of tunnel construction. Bored tunnels allow sites of high nature conservation value to remain undisturbed and are least damaging environmentally. Cut-and-cover tunnels may be more appropriate for sites of lower conservation interest, but where the maintenance of connectivity between habitats is desirable.

Use of vegetation

At the design stage it is important to understand the type of vegetation and species composition that is appropriate to the setting of the new transport infrastructure. Integration with the landscape, nature conservation benefit and passenger interest are key considerations. Where possible, species included in planting designs should be locally indigenous (especially in rural areas) and occur naturally on the soil type adjacent to the route. They should not require irrigation for successful establishment. Where suitable, natural regeneration should also be considered as an alternative method for vegetating new landscapes. Allowing vegetation to regenerate naturally will produce a habitat most suited to the local surroundings.

6. AVOIDING AND REDUCING MORTALITY

One of the major risks for traffic safety that could cause traffic accidents is the occurrence of wildlife, especially bears, on the road. Therefore, it is necessary to work constantly on the separation of transport and animals, in order to reduce the possibility of traffic accidents with serious consequences or even with the loss of human lives.

The following actions are aimed at preventing wildlife access to roads. On their own they act as a barrier and so they further add to the barrier effect of the roads. To prevent that, they should always be used together with crossings, to direct animals towards and through the structure where they can safely cross the structure.

Fences

Fences and walls may have serious barrier effects as well as a significant effect on the appearance of the road in the landscape. Their use should be restricted to specific infrastructures where they are absolutely necessary. Fences are erected to prevent access of animals to roads and reduce accidents due to collisions, especially between large mammals and cars. High speed roads or railway lines have a high risk of accidents, so they are usually fenced along the entire length, while roads with low traffic density should only have fences on high risk spots. Ends of the fences are danger points as animals may go around the end of the fence and get trapped on the road. For this reason fences should always end at structures like bridges or where only a stretch of road is fenced, it should be extended 500m or more beyond the danger area. Fences should be erected close to the road if possible, to reduce the amount of area inaccessible to the wildlife. The disadvantage of fences is that they increase the barrier effect, so plenty of places where animals are able to cross should be available. Combined with wildlife passages they serve as a guiding lines to crossing points. Where there is a danger of animals getting trapped on the road, exits should be provided to allow escape.

Conventional wildlife fences consist of wire mesh fixed with poles. Height and mesh size depend on the target species. Height should be such that animals can't jump over it, while at the bottom, mesh has to be fixed to prevent animals from going under it. For areas with snow cover, minimum height has to be guaranteed in winter and top wire of the netting must be reinforced with a cable capable of bearing snow weight. Wire mesh should be fixed on the side of the poles away from the road to prevent mesh from falling away when large animals crash into the fence. Metal or wooden posts are both suitable, providing they are strong enough to withstand the impact of animals. End poles should have a diameter of 10-12 cm when made from wood and 5-6,5 cm when steel. All posts must be firmly embedded in the ground (70cm or more). Electric fencing has also proved very effective against bears. . But as they are expensive and need regular maintenance, they are only suitable temporarily to train animals to change their habits after a new road is built.

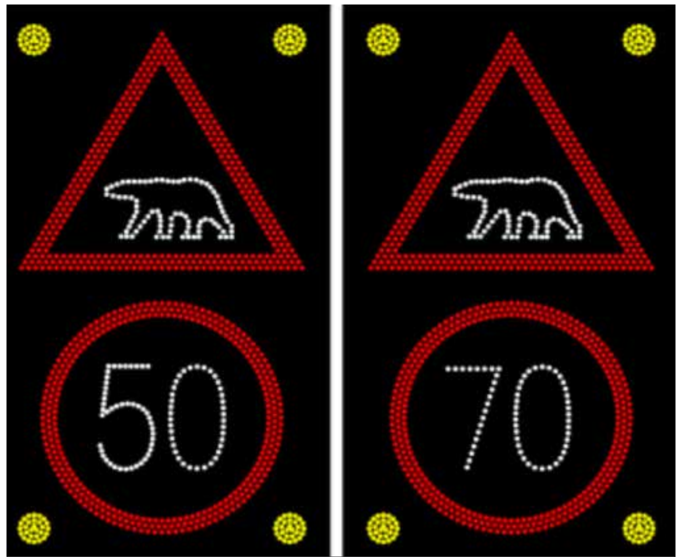
Conventional fences for large mammals may not be suitable to contain bears. Specific bear fences should be installed in sections where they may be present. The most effective proved 8x10 cm triple chain link mesh with 2.7mm wire, a height of 3m and 80cm outrigger on a 45°angle pointing away from the road. The bottom of the fence must be reinforced with a 1.5m wide horizontal mesh skirt, buried on the outer side of the fence to prevent bears from digging underneath. The fence posts (60mm in diameter and 4mm thick) must also be reinforced (Ministry of Agriculture, Food and the Environment. 2016).

By improving upon existing mitigation measures, we can improve permeability of the crossing structures and reduce traffic mortality even on existing road infrastructure. (Reljić S.)

Blocking access to motorways and deterring bears from visiting or lingering at critical parts of highways, we can greatly reduce mortality caused and improve demographic sustainability of certain sub-populations. (Huber Đ.)

Fence maintenance is important part of reducing traffic mortality on motorways as well as ensuring safety of people in traffic. (Huber Đ.)

All highways in Slovenia and Croatia are fenced on at least one side with a 160 cm high fence. At some critical section, where bear presence is regular, electrical fences can be added to prevent bears from crossing. (Potočnik H.)



Dynamic traffic signalization uses sensors to detect when animals are present near roads. As they are only activated when animals are present, drivers are more aware of them than with classical signalization.

Fence inspection has to be part of the regular road inspection at least once a year and more frequently during the first year. Holes or other damages need to be repaired immediately and particulate attention should be paid to trails which indicate the regular passage of animals.

Dynamic sign systems with sensors

Classic warning signs proved to be ineffective as they have little or no impact on mortality rates. Research suggests that drivers don't slow down after passing them, often they don't even notice them. Dynamic traffic signs are a fairly new way to alert and slow down drivers in order to avoid potential collisions with wildlife, including bears. They are called »dynamic« because they are activated by large animals that go into the dangerous area of the road and intersect the sensor beam. To increase their effectiveness warning signs combined with various sensors like heat sensors, seismic ground vibrations or breaking of laser- or infrared beams along the verge are used. Sensors are placed in the close vicinity of roads and detect approaching mammals up to 250m away. Signs are thus only activated when wildlife is in close proximity to the road.

This approach also requires for people to be informed about the meaning of illuminated signs. By knowing it represents an immediate potential danger, they will adapt their behavior. Regular checks are needed to ensure the technical equipment is working properly. Wildlife warning signs should be placed only in places where there is a high risk of collisions, because the more widespread they are, the less people pay attention to them. The effectiveness is further enhanced if signs are marked with flashing lights or a flashing speed limit sign, which are lit only during periods of high animal activity.

Bear proof garbage bins

In search of food, bears are often attracted to anthropogenic food sources. When such sources are near regional roads or highways, risk of bear-vehicle collisions increases. Bears visiting rest stops on highway is not a big problem in Slovenia and occasional problems occur on the main roads of Notranjska region. However, in Croatia it accounts for a third of all vehicle collisions on Croatian highways (Jerina et al. 2012, cit po Jerina et al. 2015).

Artificial deterrents

Acoustic deterrents are technologies used to keep animals away from targeted area. Applications of the technology for transport infrastructure are used to keep mammals from the dangerous zones along roads decreasing number of wildlife-vehicle collisions. Most experience is related to abundant large mammals, ungulate-vehicle collisions, which proved to be more or less efficient, depending on species, season and regional characteristics (Jelenko et al. 2013). In the past, in Slovenia, an assessment was made of the effectiveness of sound and other deterrents, which had a positive effect on the reduction in the number of collisions of vehicles with large mammals, but their influence, probably due to habituation of animals to stimuli, decreased over the years (Pokorny et al. 2008).

Wildlife warning reflectors are widespread. They consist of various types of reflective/metal strips placed around trees or other structures. The light of approaching vehicles is reflected towards the side of the road, which should warn animals and stop them from entering the road. These features are popular because they are cheap and easy to place. However, a thorough analysis of studies carried out over the last 40 years all over the world found little evidence for the effectiveness of wildlife warning reflectors. Reflectors also require a lot of maintenance.

Olfactory repellents are a measure to prevent accidents, mainly involving deer. Natural or artificial substances, usually a mix of scents from humans, wolves and other predators, are injected into a foam as a carrier substance which is then applied to trees or posts in the vicinity of the roads. Some experiences indicate that the number of collisions with cars is reduced, however this measure is likely not effective for bears as predators, however further research is needed in this field.

Organic waste at traffic stops in Croatia attracts bears and increases risk for bear – vehicle collisions. To decrease that and deter bears, bear-proof bins have been set at critical sections. (Huber Đ.),(Reljić S.)

Escape doors and jump-out ramps

Highways, motorway or fast railway lines with a high risk of wildlife collisions are usually fenced. Despite that, animals, especially bears that are able to climb over fences, can still get inside the fenced areas. In such cases, it is important to ensure that the animal can leave the enclosure as soon as possible, in order to reduce the risk of collision with vehicles. Construction of one-way escape doors and jump-out ramps in such situations can significantly reduce the number of traffic accidents with animals and increase traffic security. Ramps should be of the same height as wire fence to make possible the escape of any bear or other wildlife that would enter the fenced area of highway or motorway.

Acoustic deterrents deter wildlife from areas with roads. They can be placed on traffic posts. (Zaluberšek M.)

Managing vegetation alongside the infrastructure

Different ways of designing and managing vegetation alongside roads and railway lines are used with the aim of reducing the number of collisions. Some are designed to prevent animals from moving onto the road surface by attracting animals elsewhere, others by influencing the behaviour of animals or by making animals more visible.

The cutting of bushes and trees within a 3-10 m strip alongside the road reduces the attractiveness for large mammals such as red deer. At the same time the visibility of the animals to drivers is improved, which may be applicable to bears, too. The measure is mostly designed to reduce the number of collisions between large mammals and cars. This measure is suitable for roads with low traffic load and for railway lines. Hedges along fences can lead animals towards fauna passages.

Escape exit doors and jump-our ramps are used to allow animals that have managed to get onto fenced motorways a quick and safe exit from dangerous area. (Huber Đ.)

7. ECOLOGICAL COMPENSATION

Despite good planning and use of mitigation measures aiming to avoid or reduce adverse impacts on natural habitats, it is impossible to completely avoid the negative effects of infrastructure development. This realisation has led to the principle of ecological compensation in many European countries. Ecological compensation implies that specified natural habitats and their qualities, such as wetlands or old-growth forests, should be developed elsewhere when they are impacted by an approved project. When compensation is implemented, the measures should balance the ecological damage, aiming for a 'no net loss' situation that benefits both habitats and their associated species. Ecological compensation may be defined as creating, restoring or enhancing nature qualities in order to counterbalance ecological damage caused by infrastructure developments. Ecological compensation aims to enhance the role of nature conservation interests in project planning and decision-making, and to pursue a 'no net loss' solution once development is approved. These aims imply that ecological compensation is a 'last resort' solution - it is only considered where planning and mitigation measures are not able to prevent damage. Ecological compensation should not be considered as an enabling activity to allow developers to get planning permission by buying-off environmental objections. Since legal instruments, such as expropriation tools, that enable developers to acquire suitable land from landowners for compensation purposes are few, compensatory measures are mainly implemented on a voluntary basis, rooted in agreements between project developers, nature conservation trusts, landowners or other stakeholders.

Compensatory measures are fundamentally different from the protection or enhancement of natural values (nature conservation policy). However, compensatory measures must be in line with local and national nature conservation targets. In contrast with landscaping and mitigation measures, ecological compensation is generally undertaken outside the highway management area. As initiators of projects are held responsible for the implementation of the compensatory measures, highway agencies should put serious effort into acquiring land in the neighbourhood of the infrastructure for compensation objectives. By locating the compensation sites properly, for example spatially linked to nature reserves or networks, ecological functions and relations may be protected or enhanced.

Compensatory measures may include conversion of land for the development of new habitats (woods, river beds, etc.). Habitat enhancement may also encompass the adaptation of farming activities towards nature conservation considerations (e.g. meadow-birds or plants). Artificial wetlands (not necessarily ponds) may be created in order to attract species such as amphibians and reptiles. Created wetlands may not compensate for the impacted wetlands from a landscape-ecological point of view. Research enabling compensation to be targeted for the benefit of specific species can also be considered as compensation. Ecological compensation can be applied to the complete spectrum of impacts, including habitat degradation (habitat is still present, but impacted), and loss of functions such as nutrient and energy flows. In the case of a bear, it is difficult to talk about measures that could be used as compensatory, as its spatial needs are so large that they can not be offset by alternative measures. Certainly, with some measures that create habitat islands (e.g. overgrown meadows, forest patches) or line structures (hedges, hedgerows), the connectivity of the area can be improved in places where roads further reduce the connection between the two habitat patches.

8. MONITORING AND EVALUATION

After the construction of roads, railways, waterways, urban and industrial areas the application of monitoring is of crucial importance as it is this mechanism that allows planners to check the effectiveness of measures which have been applied in order to reduce the infrastructure's impact on habitat fragmentation. A well-designed monitoring scheme will help to establish if the mitigation measures fulfil their purpose and to evaluate if the measures provide long term mitigation for the species and habitats.

In short, monitoring will contribute to establishing whether or not suitable and sufficient mitigation measures have been provided for during the planning and construction phases of a transport infrastructure, guaranteeing minimum impact on the fragmentation of animal populations and habitats. The dissemination of the results of the monitoring programme is also very important for gaining knowledge on the development of more effective and less expensive measures. In general, monitoring should consist of regularly repeated measurements of selected variables. We can measure effectiveness of crossing passages and other mitigation measures that enhance connectivity or monitoring the effects of measures on species and habitats, so called ecological monitoring. The first type of monitoring focuses on the inspection and control of the effectiveness of measures by measuring local variables such as the number of animals using a passage or the number of animals run over per distance unit of infrastructure. Monitoring can be focused on an isolated measure but more often than not it is advisable to monitor the measures which show interrelationships or have a combined effect to achieve the same objective. This type of monitoring can be included in the routine management and maintenance plan of the infrastructure.

Tracking and snow tracking still remains an important part of monitoring and evaluating permeability of road infrastructure for mammals. (Reljić S.)

For better insight into use of crossing structures by mammals, different methods can be used. Collecting scat for genetic analysis (left) (Reljić S.) or use of sensors that measure the frequency of crossings. (Petkovšek S.)

The second type of monitoring, referred to as ecological monitoring, focuses on the effects of measures on particular species and its/their habitats. It focuses on the ecological effects of mitigation and compensation measures. It tries to identify changes in genetic diversity, genetic structure, genetic flow, species distribution, and population dynamics. Selected habitat features,

Sand beds together with sensors and camera traps can very effectively measure wildlife activity across motorways and crossing structures and allow us to differentiate species and sometimes even individuals.

landscape patterns and natural processes are registered after the construction of a new transport infrastructure and compared to baseline conditions.

Ecological monitoring mostly requires long-term and large-scale approaches, which take into account the whole number of measures that have been applied and the synergistic effects that occur when new transport infrastructure is added to the existing network. For this reason, this type of monitoring should be applied as routine in special cases, for example when a wildlife overpass or green bridge has been constructed to link the habitats of endangered species or other ecologically important areas.

Some of the aspects of ecological monitoring are (1) incidence of mortality caused by road and railway collisions and their effect on the population dynamics (viability) of target species. (2) Evaluation of the barrier effect of the entire infrastructure network, taking into account not only the proportion of animals that try to cross and are run over but also the proportion of individuals that attempt the crossing and are deterred from doing so by disturbance such as traffic/urban noise or light. Ecological monitoring provides very valuable information for the design of new infrastructure in order to mitigate its effects, and also improves understanding of the problems. The design of these monitoring projects must be carried out by wildlife/species experts because methods and temporal and spatial scale of measurements show a high variation between different species and landscapes.

A large number of methods can be used to monitor mitigation measures. The most common methods for recording fauna casualties and checking the use of fauna passages are: (1) recording of road and railway mortalities, (2) registering the proportion of animals that succeed in crossing the transport infrastructure (snow tracking) and (3) monitoring the use of fauna passages by recording animal tracks on sand/ink beds and/or using foto/video-traps.

Bear tracks on sand beds (left) used to monitor effectiveness of crossing structures. Modern camera traps (right) can detect animal passing during day as well as nighttime using 940 nm IR light which is invisible for mammals. (Potočnik H.)

Sand beds on green bridges are often combined with animal counters, which allow the evaluation of the frequency of the passage of individual animal species, based on footprints that are recorded in the sand. (Huber Đ.)

To monitor the frequency of animal crossings on new structures and use by species, different methods can be used: genetic sampling (hair/scats), road kill or vehicle collision data, snow tracking, tracking beds or plates, digital camera and video monitoring, GPS telemetry or VHF radio monitoring, active and passive IR trail monitoring system. To compare the efficiency of the crossing structure, monitoring should be conducted before and after construction. Best results are achieved by using a combination of methods.

For track pad monitoring track paths are set up spanning the whole width of the bridge. It is recommended to use finer sands as species are easier to determine. Regular monitoring of the trackpads is necessary especially in the bad weather. Although we can determine the number of crossings using this method, we can't determine the number of individuals that crossed, so to monitor that, other methods have to be used (camera traps, genetics).

Gužvica et al. (2014) tested three different methods: track pad monitoring, active IR trail

Surveillance cameras have caught bear attempting to cross fenced highway Zagreb – Rijeka, close to the tunnel Sleme. (ARZ)

Capture and GPS telemetry allows us to closely monitor bear behavior and effects of motorways and other human activities on bears and their use of space. (Krofel M.)

monitoring and digital camera trap monitoring. Results show that camera traps are very reliable but not suitable for monitoring fast moving species and tracking beds also proved to be reliable when using higher proportion of fine grained materials.

Standard infra-red detectors, also called trail traffic counters, can be used to determine the number of animals using the passage. The movement of an animal activates the counter and records the total number of animals that have used the structure during a set period. The detectors are fixed to the walls of fauna passages or culverts and some of them can be modified to record the movement of small animals and to register the date and time of movements. The disadvantage of this method is that the species is not recorded so that the information provided is of limited value.

Examining the recordings of security or traffic control video cameras. Some overpasses, tunnels or waterways have CCTV cameras to monitor traffic and security. Recordings often contain images of animals that cross the causeway or are near the transport infrastructure. This information can be used to detect inappropriate use of fauna passages, the failure of fences or other information related to animal behaviour with respect to transport infrastructure.

Marking animals with satellite/VHF receivers/transmitters/collars can provide much more information than other types of data about the behaviour of the animals in relation to the traffic infrastructure. The received data provides information about the movement of the animals, their home range and the location of infrastructure crossing points. This method has been mostly used when endangered or charismatic species like bears, wolves or lynx were involved because it requires a substantial investment of time and money both to capture the animals and to monitor their movements.

Rapid development of wildlife telemetry techniques based on GPS telemetry and molecular genetics over the last couple of decades provided a new set of tools that are in many ways revolutionizing the way we study, monitor and manage populations of threatened species. Especially important

With development of modern genetic tools that allow individual recognition by use of noninvasive samples (scat, saliva, hair), monitoring of the use of crossing structures and gene flow between habitat patches, is much easier. (Potočnik H.)

methodology for planning, monitoring and assessing impacts of new development including transport infrastructure on bears is emergence of habitat suitability modelling in GIS and landscape genetics, a recent discipline that looks at genetic connections between individuals, subpopulations and populations from a spatial perspective and tries to understand how they are affected by characteristics of the underlying landscape. Together with the habitat suitability model for e.g. bears, these data can be used to assess connectivity between habitat patches, effects of linear barriers (e.g. roads, highways, large rivers) and produce a connectivity models of the study area landscape from the bear perspective.

As studies show that some species need an adaptation period when they are learning how to cross or acclimate to the new structure, one or two year monitoring is too brief to provide reliable results. Studies of four (5) or more years are therefore more suitable.

9. EXAMPLES OF SUCCESSFUL PRACTICE

Banf National Park, Canada

Banf National Park was established in 1885 and now covers 6641 km2. Because of Trans-Canada highway, a four lane highway, that bisects the park and the parks efforts to reduce wildlife mortality and increase population connectivity, it has been among the testing sites for wildlife crossings to mitigate the effects of roads on wildlife since 1982. Since then scientists have followed and monitored parks' wildlife and their response to the structures using field work, tracks, cameras and genetics. This resulted in one of the largest and longest (time wise) data sets on the world. Currently there are 45 wildlife crossing structures (6 overpasses and 39 underpasses) and 166 km of highway fencing.

Results of implementation of mitigation measures for reduction of bear mortality and enhancing permeability on Zagreb – Rijeka highway

In Croatia, planning for wildlife crossing structures began over ten years ago when during a project on bear protection, possible habitat fragmentation due to planned motorway became a great concern for researchers. Since then a lot of research has been done, and several crossing structure projects have been put into practice, and guidelines for the planning and for the suitability of different structures for animal crossing have been developed. In total 25.2 % of Zagreb-Rijeka highway, 17.9% of highway in Lika region and 8.3% of Dalmatia highway have structures that allow animal crossings (tunnels, viaducts, bridges and green bridges). Research shows that large mammals of Gorski Kotar preffered wider overpasses (100m or more) to narrow underpasses (10-50m) (EuroNatur, 2010).

Modern Croatian motorways have a relatively good permeability for large mammals due to the diverse relief and consequently a large number of tunnels and viaducts, as well as due to a modern nature protection approach in planning mitigation measures. (Huber Đ.)

The relationship between bears and roads is two-fold: if on the one hand bears generally avoid roads frequently used by humans, they can also show occasional attraction towards these structures due to the presence of killed animals or trash (Huber et al. 1998; Roever et al. 2010). Thus, roads can represent ecological traps to bears (Penteriani 2018). Bear-vehicles collisions are the second most important cause of bear mortality in Slovenia and Croatia and constitute a threat to human safety as well (Huber et al. 1998; Kaczensky et al. 2003; Kusak et al. 2009). For this reason, the implementation of effective mitigation measures that will keep bears away from roads, highways and railroads, while maintaining landscape permeability, it is important both to make roads safer and for bear population management (Kusak et al. 2009; van der Grift et al. 2013).

The highway from Zagreb to Rijeka stretches 68.5 km through a wildlife core area in Gorski kotar (Croatia). It has 43 viaducts and tunnels, and one specifically constructed (100 m wide) green bridge (Dedin). One quarter of the total highway length consists of possible crossing structures. They counted animal tracks under one viaduct, over two tunnels and one green bridge on the highway through the large carnivore core area in Gorski kotar. Tracks were searched as footprints in snow, mud or sand, or as scats, digging sites and specific marks on trees or ground. At Dedin green bridge, a total of 12,519 crossings have been recorded during 793 different days of active infrared monitors being in operation, or 15.8 crossings per day. Two monitored tunnel overpasses had 11.2 and 37.0 crossings per day, respectively, whilst 4.3 crossings occurred per day under one monitored viaduct. Of those crossings, 83.2% were by ungulates and 14.6% by large carnivores. Radio-tracked large carnivores, brown bear (Ursus arctos), grey wolf (Canis lupus) and Eurasian lynx (Lynx lynx), expressed strong positive selection for tunnels and viaducts, whilst avoiding small underpasses or bridges. Selection for the use of Dedin green bridge was equal to its availability. We conclude that this green bridge, constructed as a measure to mitigate the negative effects of the studied highway, served its purpose acceptably. Territorial and dispersing radio-tracked large carnivores crossed the highway 41 times, using both sides of the highway as parts of their home ranges.

Electric fence has been installed along both sides of the problematic motorway section Rijeka-Zagreb regarding bear mortality. In total, more than 35 km (more than 70 km considering both sides)

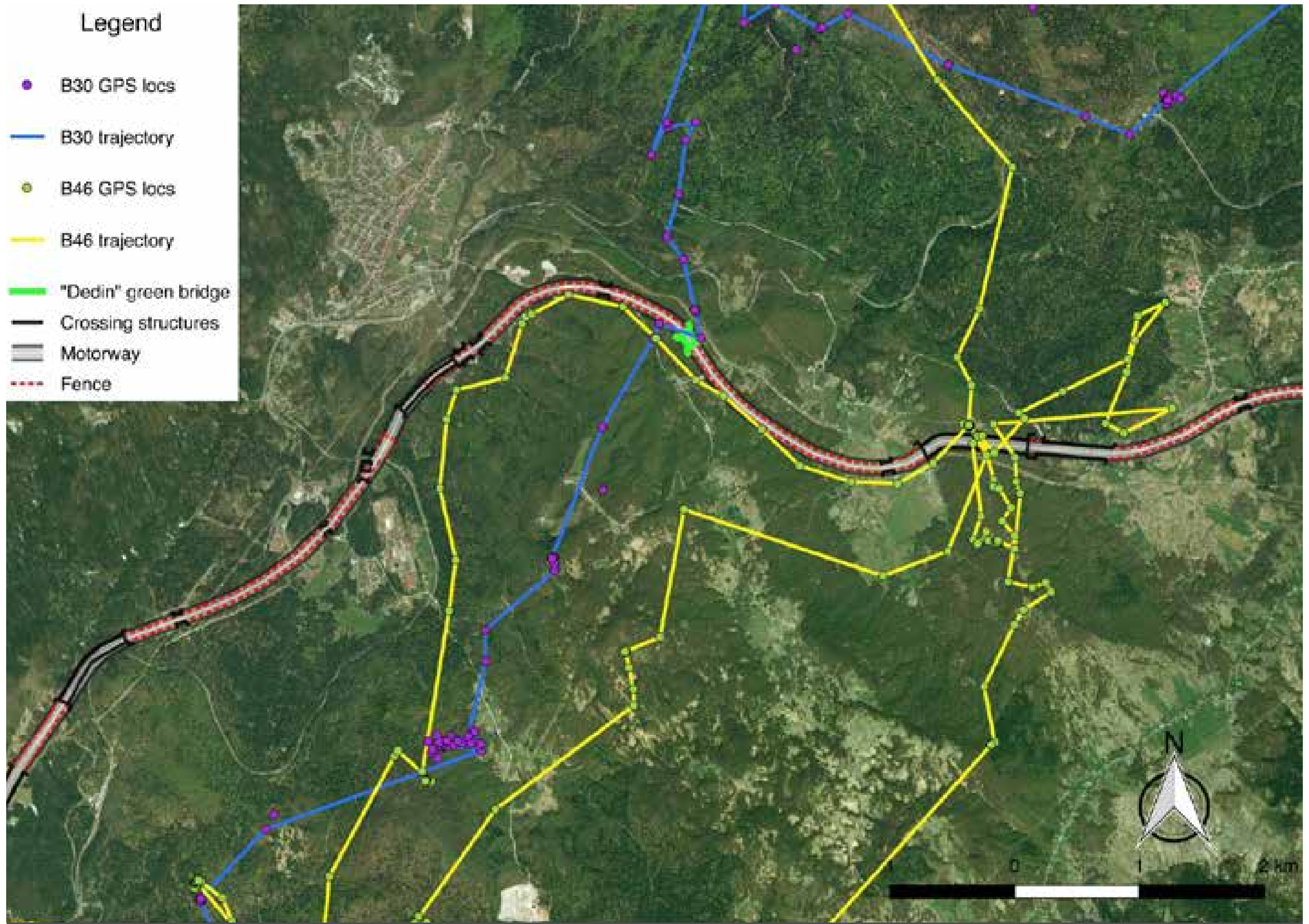
Monitoring the effectiveness of jump-out ramp that allows animals that do manage to get onto fenced motorway Zagreb - Rijeka, to quickly leave the area. (Huber Đ.)

View from green bridge Dedin to the north edge of the crossing structure. Part of the forest has been cut down which reduces the use of crossing structures by animals. (Huber Đ.)

of five wired (different heights) electric fence has been installed beside the already existing wire mesh protecting fence. In this part of the highway section from Karlovac to Rijeka, due to the rugged configuration of the terrain, there is a large number of tunnels, viaducts and other possible places of wildlife crossings (including one 100 m wide green bridge), which should satisfy the requirements relating to the natural movements of bears.

Here we report a case of a subadult bear ("B46-Slaven2") avoiding the electric fences installed along the Rijeka-Zagreb motorway (Croatia), then walking along the highway without crossing it for 3.9 km, and finally reaching the other side of the highway passing over the "Vršek" tunnel. Although it is unknown whether the electric fence was properly provided with electricity during that day, it is probable that the fence acted as a physical barrier for the bear, and apparently redirected the animal towards safer areas for crossing. It should be noticed that the bear did not use the 100-m wide green

Installment of one way escape doors allows animals to escape from fenced motorway Zagreb – Rijeka (left). Adding electrical fencing ensures protection against bears and guides them to safe crossing locations (right). (Huber Đ.)



Movement data of collared bears (B30 and B46) show how important crossing structures and use of other deterrents (electrical fence, fence) on Zagreb – Rijeka motorway are for bears. (Kusak 2019)

bridge "Dedin" to reach the other side of the motorway lane, but preferred forested area above a 811-m tunnel. However, earlier monitoring has proven that Dedin green bridge is used as crossing structure by large and medium size mammals 15 times per day, including the crossing of 1.5 bear per day (Kusak et al. 2009). Some other tracked bears (like B30-Marko), knew where the green bridge is and were targeting it from far away, crossing it in both directions. B29 was using Sleme and Sopač tunnels most often, but it also used Dedin when it was suitable to it.

Implementation of dynamic traffic signs along the main road Ljubljana – Kočevje

Between 2015 and 2017, three systems of dynamic traffic signs were placed along three hot-spot sections of the main road Ljubljana – Kočevje (between Zgornje Lozine and Dolenja vas (Jasnica), between Ortnek and Žlebič) and south of Turjak village to alert and slow down drivers in order to avoid potential collisions with wildlife, including bears. Dynamic signs were coupled to sensors capable to detect large animals approaching to the roadways. In the case of approaching bear (or ungulates), the signs light on and send the message to the driver that an animal is approaching the road. Since the sensors are not bear-specific, they provide also higher road-safety considering collisions with other large mammals, particularly ungulates.

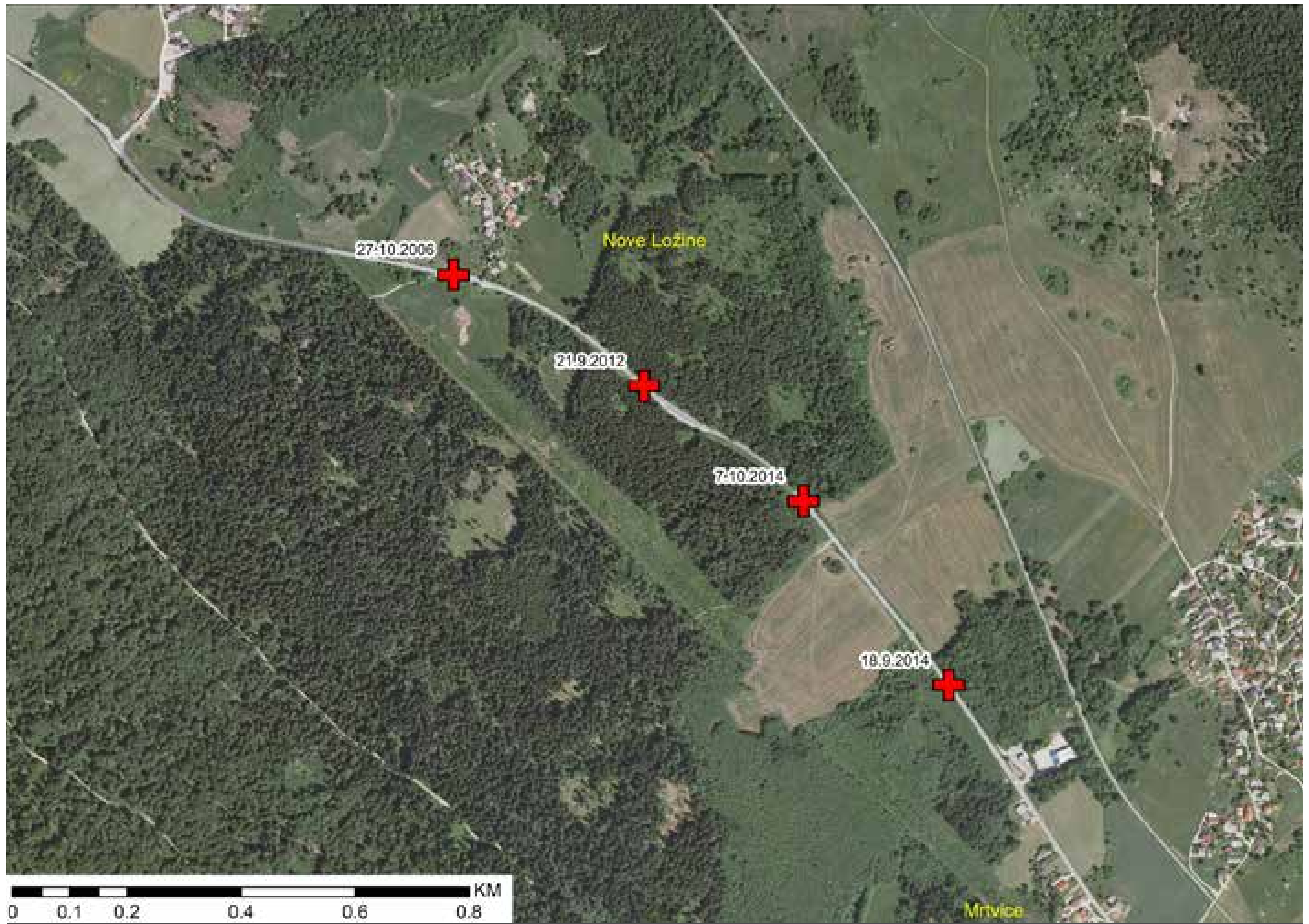
Video monitoring has been also used to monitor operating of dynamic traffic signalization systems and wildlife behavior on or near roads.

Dynamic traffic signalization on section Ljubljana – Kočevje warn drivers of wildlife presence. (Pavšek Z.)

They have monitored the impact of the activation of dynamic signs on the speed of vehicles of incoming traffic at protected sections on the main road Ljubljana - Kočevje. Traffic counter was placed on the pole with a dynamics sign. The comparison between average speed during activation and inactivation of dynamic signs showed that at both locations (Jasnica and Ortnek) speed of vehicles, passing the active dynamic signs was significantly lower in comparison with average speed of vehicles, passing the inactive dynamic signs. The reduction of average speed at particular section was from 5.5 km to 18 km/h that confirms the positive impact of activation of dynamic signs on driver's behaviour.

Installation of acoustic deterrents along selected road and railway sections in Slovenia

Acoustic deterrents (ultra- and infrasound emitting electronic devices coupled with sensors activating the sound by the approaching vehicle)



Locations on Ljubljana – Kočevje road (Nove Ložine) showed a critical point for collisions with bears and helped to determine location for dynamic traffic signalization systems to slow down oncoming vehicles and increase drivers' awareness.

Positioning sound deterrents at critical sections of railway line Rakek – Postojna and Postojna – Prestranek. (Zaluberšek M.)

were installed directly into the roadside trafficators/pillars along the 'black-spots' considering bear-vehicle collisions along the main road Ljubljana – Kočevje. In total, approximately 7.5 km of roads were protected by 240 acoustic deterrents.

At the end of 2015, acoustic deterrents were installed on electric poles along the railway sections Rakek – Postojna and Postojna – Prestranek, where it was stated by field inspection that crossing of wildlife (especially brown bear) is possible.

The traffic related bear mortality at protected main road and railway during five year-period (from 2011 to 2015), before countermeasures were implemented, nine bears were road killed at relevant sections of main road Ljubljana - Kočevje which on average amounts 1.8 mortality bear cases per year Afterwards, when acoustic deterrents were installed in 2016 and dynamic traffic signs were placed near the most problematic road sections or "hot spots" the bear mortality on mentioned road sections declined to 1 or 0 bears per year. This means that the reduction to 0.7 road mortality cases per year is so far more than 50 %.

In the same period 2011 to 2015, before installation of acoustic deterrents, 15 mortality cases (on average 3 per year) of brown bears were registered at relevant railway sections between Ljubljana and Pivka. The result of the countermeasures in subsequent years was favourable, since the reduction of the bear railway mortality was more than 50 %. Before, the railway mortality was 0 to 8 bears per year, after the implementation, the mortality was 0 to 2 animals per year (1.3 on average).

10. REFERENCE

1 Chapron, G., Jerina, K., Kos, I., Krofel, M.a, Majić Skrbinšek, A., Potočnik, H., Skrbinšek, T., et al. Recovery of large carnivores in Europe's modern human-dominated landscapes. Science, ISSN 0036-8075, 19. Dec. 2014, vol. 346, iss. 6216,. 1517-1519, doi: 10.1126/science.1257553

2 Chisholm M., Bates A., Vriend D., Cooper D., 2010. Wildlife passage engineering design guidelines.

3 Clevenger AP, Huijser MP, 2011. Wildlife crossings structure handbook. Design and evaluation in North America

4 Černe R., Bartol M., Ferjančič Lakota T., Groff C., Huber Đ., Jerina K., Knauer F., Majić Skrbinšek A., Reljić S., Skrbinšek T. 2017. Guidelines for Common Management of Brown Bear in the Alpine and Northern Dinaric Region. Guidelines prepared within A.6 action of the LIFE DINALP BEAR project (LIFE13 NAT/SI/000550).

5 Direktoratet for Naturforvaltning (2002). Slipp fisken fram! Fiskens vandringsmulighet gjennom kulverter og stikkrenner. DN Handbok 22-2002.

6 EuroNatur, 2010. TEWN Manual. Recommendations for the reduction of habitat fragmentation caused by transport infrastructure development. EuroNatur Foundation. Radolfzell.

7 Green Bridges: A literature review (NECR181), Natural England, July 2015, 56pp.

8 Gužvica G, Bošnjak I, Bielen A, Babić D, Radanović-Gužvica B, Šver L (2014) Comparative Analysis of Three Different Methods for Monitoring the Use of Green Bridges by Wildlife. PLoS ONE 9(8): 186-194.

9 Huber D., Kusak J., Frkovic A., 1998. Traffic kills of brown bears in Gorski Kotar, Croatia. Ursus 10:167-171.

10 Huber Đ., Jakšić z., Frković A. et al. 2008. Brown Bear Management Plan for the Republic of Croatia. Ministry of Regional Development, Forestry and Water Management, Directorate for Hunting Ministry of Culture, Directorate for the Protection of Nature: 92 pp.

11 Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavác, V., Keller, V., B., Rosell, C., Sangwine, T., Tørsløv, N., Wandall, B. le Maire, (Eds.) 2003. Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions. Habitat Fragmentation due to Transportation Infrastructure. (COST 341).

12 Jelenko, I., Poličnik, H., Pokorny, B., 2013. Monitoring in analiza učinkovitosti izvedenih ukrepov za preprečevanje trkov vozil z divjadjo [Monitoring and analysis of the effectiveness of counter measures implemented for preventing game-vehicle collisions] [In Slovene]. Report for Slovene Directorate for Roads, Contract no. 2415-11-001267/0. ERICo Velenje, 246 pp.

13 Jelenko Turinek I., Petkovšek S.S, Pavšek Z., 2018. Monitoring of the effectiveness of mitigation measures in Slovenia. LIFE DINALP BEAR (LIFE13 NAT/SI/000550): Population level management and conservation of brown bears in northern Dinaric Mountains and the Alps.

14 Jerina K. 2002. The strategy and dynamics of brown bear expansion in Slovenia in post World War II period. Biotechnical Faculty, Department of Forestry, Ljubljana, Research Report 2/2002:1–31 (in Slovene).

15 Jerina K., Adamič M., 2008. Fifty years of brown bear population expansion: effects of sex-biased dispersal on rate of expansion and population structure. Journal of Mammalogy, Volume 89, Issue 6, 16 December 2008, Pages 1491–1501, https://doi.org/10.1644/07-MAMM-A-357.1

16 Jerina K., Jonozovič M., Krofel M., Skrbinšek T., 2013. Range and local population densities of brown bear Ursus arctos in Slovenia. European Journal of Wildlife Research 59(4):1-9 August 2013, DOI: 10.1007/s10344-013-0690-2

17 Jerina K., Krofel M., Stergar M., Videmšek U., 2012. Preučevanje dejavnikov habituacije rjavega medveda na človeka z uporabo GPS telemetrije. Končno poročilo. Univerza v Ljubljani, BF, 18 pp.

18 Jerina K., Ličina T., Krofel M., Reljić S., Huber D., Jonozovič M., Stergar M., 2015. Impact of bear-vehicle collisions on Slovenian-Croatian brown bear population and its expansion into Alps. LIFE DINALP BEAR (LIFE13 NAT/SI/000550).

19 Jerina K., Krofel M., Mohorović M., Stergar M., Jonozovič M., Anthony S. 2015a. Analysis of occurrence of human-bear conflicts in Slovenia and neghbouring countries. Report Action A4. LIFE DINALP BEAR, LIFE13 NAT/SI/000550; 44pp.

20 Kaczensky P., Knauer F., Krze B., Jonozovič M., Adamič M., Grossow H., 2003. The impact of high speed, high volume traffic axes on brown bears in Slovenia.

21 Krofel M., Jonozovič M., Jerina K., 2012. Demography and mortality patterns of removed brown bears in a heavily exploited population. Ursus 23(1):91–103 (2012)

22 Krofel, M., Jerina, K., 2012. Pregled konfliktov med medvedi in ljudmi: vzroki in možne rešitve. Gozdarski vestnik, 70/2012, št. 5–6.

23 Kusak, J., Huber, D., Gomerčić, T. et al. 2009. The permeability of highway in Gorski kotar (Croatia) for large mammals. Eur J Wildl Res (2009) 55: 7. https://doi.org/10.1007/s10344-008-0208-5

24 Ministry of Agriculture, Food and the Environment. 2016. Technical prescriptions for wildlife crossing and fence design (second edition, revised and expanded). Documents for the mitigation of habitat fragmentation caused by transport infrastructure, number 1. Ministry of Agriculture, Food and the Environment. Madrid. 124 pp.

25 Petkovšek S., Pokorny B., Pavšek Z., Jerina K., Krofel M., Ličina T., 2015. Action plan for the implementation of mitigation measures for reducing road mortality of brown bear in Slovenia. LIFE DINALP BEAR: Life 13 NAT /SI/000550: Population level management and conservation of brown bears in northern Dinaric Mountains and the Alps.

26 Pokorny, B., Marolt, J., Poličnik, H., 2008. Ocena učinkovitosti in vplivov zvočnih odvračalnih naprav kot sredstva za zmanjšanje števila trkov vozil z veliko divjadjo [Assessment of the effectiveness and impacts of acoustic deterrents as a countermeasure for reducing the number of big game vehicle collisions] [In Slovene]. Final report for Slovene Hunters Association, Contract no. LZS- 04/1298. ERICo Velenje, 107 pp.

27 Roever, C., M.S. Boyce, and G.B. Stenhouse. 2010. Grizzly bear movements relative to roads: application of step selection functions. Ecography 33:1113-1122.

28 Simonič A. 1992. The legal protection of the brown bear in Slovene territory—past and present, and some suggestion for the future. Pp. 43–76 in Rjavi medved v deželah Alpe-Adria: Zbornik posvetovanja, Ljubljana, 29. in 30. junija 1992 (M. Adamič, ed.). Gozdarski Inštitut Slovenije, Ljubljana, Slovenija.

29 Skrbinšek T., Jelenčič M:, Potočnik H., Trontelj P., Kos I., 2008. Analiza medvedov odvzetih iz narave in genetsko-molekularne raziskave populacije medveda v Sloveniji. Zaključno poročilo, 1.del: Varstvena genetika in ocena številčnosti medveda 2007. Univerza v Ljubljani, Biotehniška fakulteta, 79 pp.

30 Swenson J.E., Gerstl N., Dahle B., Zedrosser A. 2000. Action plan for the conservation of the brown bear (Ursus arctos) in Europe. Council of Europe, Strassburg, France.

31 Swenson J.E., Sandegren F., Söderberg A., 1998. Geographic expansion of an increasing brown bear population: evidence for presaturation dispersal. Journal of Animal Ecology 67:819–826.

32 van der Grift, E.A., van der Ree, R., Fahrig, L. et al. 2013. Evaluating the effectiveness of road mitigation measures. Biodivers Conserv (2013) 22: 425. https://doi.org/10.1007/s10531-012-0421-01.

Title, subtitle: Handbook for integrating the bear habitat suitability and connectivity to spatial planning

Editor: Hubert Potočnik

Authors: Hubert Potočnik, Samar Al Sayegh Petkovšek, Daniele De Angelis, Đuro Huber, Klemen Jerina, Josip Kusak, Meta Mavec, Boštjan Pokorny, Slaven Reljić, Mariano Rodriguez Recio, Tomaž Skrbinšek, Bojan Vivoda

Author of front cover photo: Lukasz Fijalkowski

Authors of photograps: Hubert Potočnik, Jan Hlačer, Jaka Črtalič, Đuro Huber, Marko Masterl, Slaven Reljić, Bojan Vivoda, Meta Zaluberšek, Miha Krofel, Samar Al Sayegh Petkovšek, Zoran Pavšek

Translation: Prevekso Jeziki d.o.o.

Graphic design and layout: Agena d.o.o.

Published by: Univerza v Ljubljani

Ljubljana, 2019

Number of copies: 400 izvodov

Print: Tiskarna P&G

About the project

Acronym: LIFE DINALP BEAR
Project title: Integrated management and protection of the brown bear in the northern Dinarides and the Alps
Reference: LIFE13 NAT/SI/000550

The electronic version of the manual is available on the LIFE DINALP BEAR website:
www.dinalpbear.eu
You can follow us also on Facebook (www.facebook.com/dinalpbear)
and Twitter (twitter.com/dinalpbear).
E-mail: dinalpbear@gmail.com

LIFE DINALP BEAR

LIFE13 NAT/SI/000550

With the support of LIFE - the European Union Financial Mechanism.