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RESTORING ECOLOGICAL NETWORKS ACROSS TRANSPORT CORRIDORS IN BULGARIA

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Abstract

Bulgaria is currently in a phase of political and socio-economic transition and faces many challenges in balancing economic and environmental interests. One of these challenges is the development of a sustainable road and railroad network that facilitates the needs for efficient transport of goods and people but does not threaten areas that are especially valuable for nature conservation. Currently plans have been developed to substantially upgrade and expand the national road and railroad network. The existing transportation corridors and the proposed extensions pose a threat to wildlife and affect the development and functionality of both a national and Pan-European ecological network. Our objective is to provide the necessary knowledge to help the Bulgarian authorities set up a national program to minimize the fragmentation effects of these expanding transportation corridors so as to preserve biodiversity and develop a coherent and sustainable ecological network across the country. The main research questions we addressed are: (1) What sections of the road and railroad network are expected to significantly affect the viability of wildlife populations? (2) Which of these ecological bottleneck locations need to be addressed most urgently? (3) What measures could be taken to solve the problems? To identify bottleneck locations in the Bulgarian road and railroad network we used a combination of two strategies. First, an expert-based GIS model – LARCH – was used to study the impact of existing and planned human transport corridors on the population viability of twelve indicator species. Second, and independent of the modeling approach, experts for all indicator species were asked to identify bottleneck locations in the road and railroad network in Bulgaria. The bottleneck locations identified by the LARCH model and the experts were mapped and analyzed for potential overlap. In total 283 bottleneck locations were identified in the existing road and railroad network of Bulgaria. About 30% of all bottlenecks are classified as *high priority* locations. Immediate action is recommended at these locations as these have been identified as locations where the impact on population viability is high and/or wildlife is frequently killed in traffic. In total 544 mitigation measures were identified as necessary to restore habitat connectivity and reduce wildlife mortality. A significant number (331) of these proposed mitigation measures involve adapting existing structures, such as road tunnels, viaducts or bridges, to allow for better use of these structures by wildlife. In addition 213 new structures, to be used exclusively by wildlife, are needed. Total costs of the proposed mitigation actions are estimated to be 132 million euro. The implementation of the here proposed road and railroad mitigation is expected to significantly improve the population viability of most threatened wildlife species and, as such, is an indispensable first step in preserving Bulgaria's biodiversity and developing a coherent and sustainable ecological network across the country.

Introduction

Urban, industrial or agricultural areas, transportation corridors, and their continued growth often affect natural areas and the wildlife that depends on these areas. The loss and cutting up of natural areas through these anthropogenic activities is commonly referred to as "habitat fragmentation". Transportation corridors, mostly roads and railroads, are among the main causes of habitat fragmentation. They not only cause the loss of natural habitats but also affect the quality of adjacent habitats, hinder the movement of ground-dwelling animals across the landscape and increase wildlife mortality through vehicle collisions. These impacts can increase the risk of (local) extinction for certain species, especially those that are already vulnerable or endangered.

The total paved road and railroad length in Bulgaria is 18,744 (outside urban areas) and 4,345 km, respectively. A considerable length of these transportation corridors cross valuable natural areas. Furthermore, in Bulgaria plans have been developed to substantially upgrade and expand the national road and railroad networks, including five Pan-European Transport Corridors. The existing transportation corridors and the proposed extensions pose a threat to wildlife and affect the development and functionality of both a national and Pan-European Ecological Network (PEEN), including the designation and protection of NATURA 2000 sites.

This study aims to identify and prioritize sections of the Bulgarian road and railroad network that are expected to significantly affect the viability of wildlife populations and provides recommendations to avoid or mitigate the problems identified (Van der Grift et al. 2008). Our research questions are: (1) What sections of the Bulgarian road and railroad network are bottleneck locations from an ecological point of view? (2) Which of these bottleneck locations need to be addressed most urgently? (3) What measures could be taken to solve the problems? The overall objective is, in these times of extensive expansion of the road and railroad systems, to develop tools to help the Bulgarian authorities set up a national program to minimize the fragmentation effects of these transportation corridors so as to preserve biodiversity and develop a coherent and sustainable ecological network across the country.

Methods

To identify bottleneck locations in the Bulgarian road and railroad network we used a combination of two strategies (Van der Grift et al. 2008). First, an expert-based GIS model was used to study the impact of existing and planned human transport corridors on the viability of wildlife populations. Second, experts were consulted for their opinion of important ecological bottleneck locations. The two methods were included and combined in the study, as the development of a national program for de-fragmentation in the Netherlands has shown that bottleneck locations are best assessed when model analyses of the viability of wildlife populations on a national scale are combined with expert knowledge of the local situation (Van der Grift 2005, Van der Grift & Pouwels 2006).

Selection of Indicator Species

Many wildlife species are affected by roads. Since it would not be feasible to analyze all the species in Bulgaria that might be sensitive to road impacts, twelve key wildlife species were selected and used as indicators to assess bottleneck locations in Bulgaria's transport network. The species were selected so as to represent all the major ecosystem types in the country. Moreover, a range of small, medium and large animal species were selected, as the barrier effect of roads can vary according to the size of the species, the size of their home ranges and their ability to move between habitat patches. The selection consisted of 8 mammal, 3 reptile, and 1 amphibian species (Table 1).

Identification of Bottleneck Locations

Step 1: Population Viability Analysis
A model (LARCH) was used to estimate the viability of the wildlife populations of each indicator species in two situations; with road and railroad barriers present and with mitigated barriers. Any significant changes in population viability between the first and second situation were identified as bottleneck locations, i.e. road or railroad sections where the existing or planned infrastructure limits population viability. These sections can be seen as the best locations for the construction of wildlife passages to restore habitat connectivity. LARCH – an acronym for Landscape ecological Analysis and Rules for Configuring Habitat – is a spatially explicit expert-based GIS model that allows for analysis of the configuration and persistence of habitat networks that can lead to viable wildlife populations. LARCH uses carrying capacity thresholds to determine whether or not these habitat networks can support viable populations. The impact of roads and railroads that form partial, or absolute, barriers to animal movements is included. The model is best used in comparative studies, as is the case here where comparisons are made between the viability levels in situations with and without de-fragmentation measures in the road and railroad networks.

The LARCH study identified sites where de-fragmentation measures may lead to a shift in population viability from non-viable (i.e. population with an extinction probability of >5% in 100 years) to either viable (i.e. population with an extinction probability of 1-5% in 100 years) or highly viable (i.e. population with an extinction probability of <1% in 100 years), and where population viability shifts from viable to highly viable, solely due constructing wildlife crossing structures. Such shifts in population viability can be achieved in different ways, i.e. by restoring habitat connectivity across different roads. In those cases the spot was chosen where habitat connectivity is highest, i.e. the locations with the highest expected exchange rate of animals between habitat patches. No bottleneck locations were identified if >95% of the populations of an indicator species in the current fragmented situation could already be categorized as highly viable. Although in these cases mitigation measures may further improve population viability, it was considered that there is no urgent need for such measures for these species. For a full description of the LARCH-methods used in the present study we refer to Van der Grift & Pouwels (2006).

Step 2: Expert Opinion
Independent of the modeling approach, experts for all indicator species were asked to identify bottleneck locations in the road and railroad network in Bulgaria. The identified spots include locations where animals are known to be killed by traffic, those where animals are known to cross the road, where physical road features inhibit road crossings, where wildlife is often seen in the vicinity of the road and where roads cross pristine areas or areas with high animal densities.

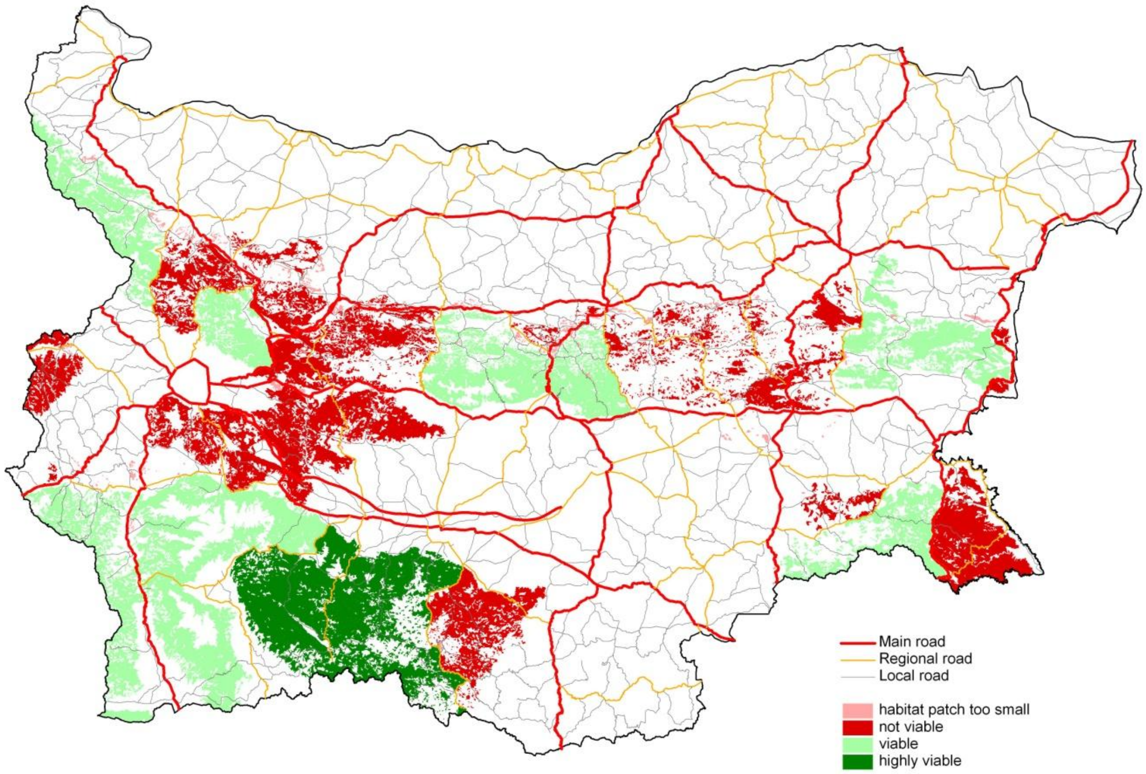
= Forest
= Woodland shrub
= Steppe grassland
= Wetland-River-Pond

Habitat area requirement (km^2)	Dispersal capacity (km)						
	<1	1-3	3-7	7-15	15-25	25-35	>35
0-0.1	Tortoises *Testudo hermanii* and *T. graeca*	Common toad *Bufo bufo*					
	Souslik *Spermo-philus citellus*	Aesculapian snake *Zamenis longissimus*					
		Blotched snake *Elaphe sauromates*					
0.1-1			Marbled polecat *Vormela peregusna*				
1-5				Wildcat *Felis silvestris*			
5-10					Pine marten *Martes martes*		
10-50					Otter *Lutra lutra*		Brown bear *Ursus arctos*
>50						Red deer *Cervus elaphus*	Wolf *Canis lupus*

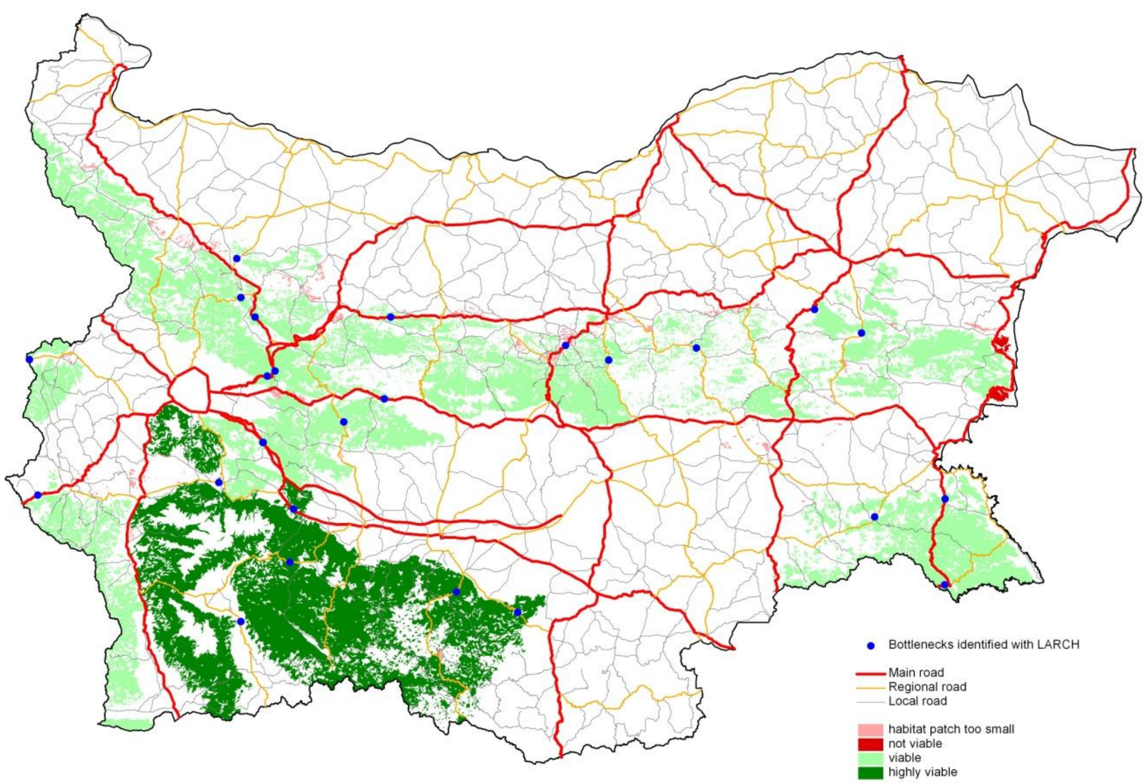
Table 1. Selected indicator species varying in home range size and dispersal capacity, representing a range of ecosystems.

Step 3: Integration
In the third step bottleneck locations identified by the LARCH model and the experts were mapped and analyzed for potential overlap. All of the unique individual bottleneck locations were then evaluated for the potential impact of de-fragmentation measures on the population viability of the indicator species.

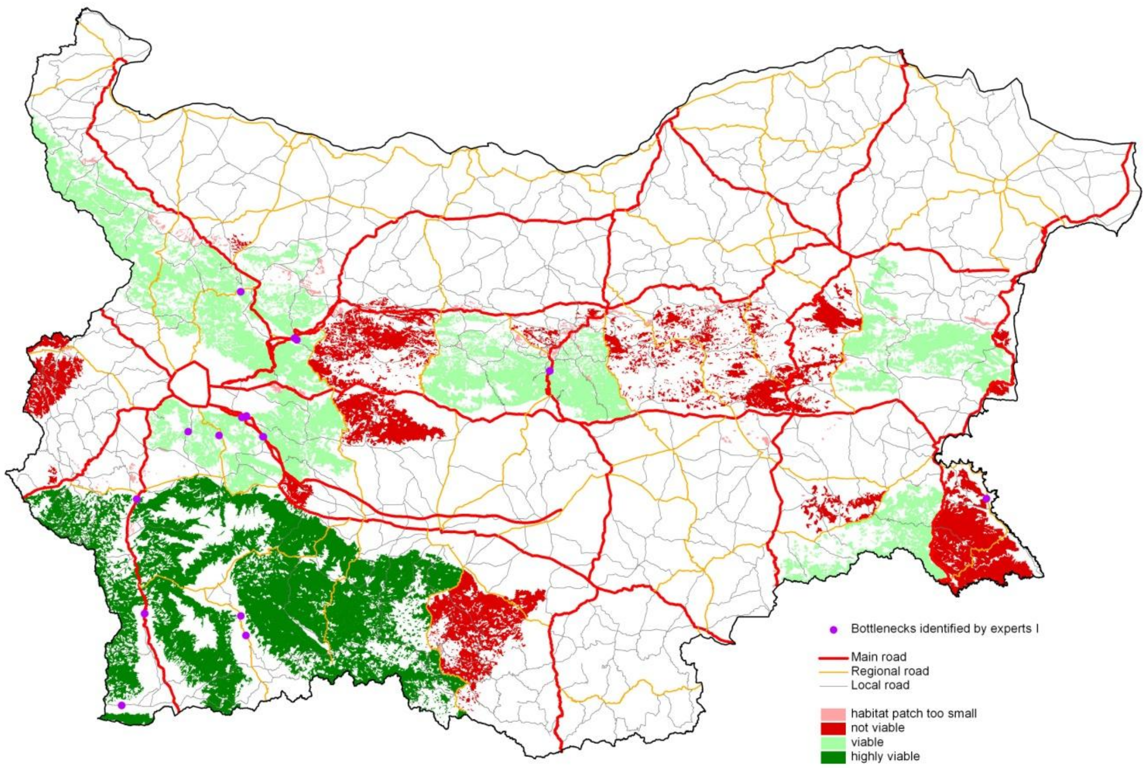
Step 4: Optimization
The LARCH model initially identifies bottleneck locations where mitigation measures are likely to have an immediate effect on population viability. In a second analysis it identifies situations where population viability will change immediately as a result of implementing road mitigation measures if identified bottleneck locations in the first analysis are all mitigated. For most species this two-step approach is sufficient to identify the most important bottleneck locations and improve population viability in most parts of their habitat. However, further improvements may be revealed through a third or fourth (‘optimization’) analysis, in which mitigation of all previously identified bottleneck locations is assumed. In this study optimization analysis was achieved by a second expert evaluation, in which additional locations for de-fragmentation were identified only if, based on the viability estimations of all initially identified LARCH and expert bottleneck locations together, further significant improvements in population viability could be reached.



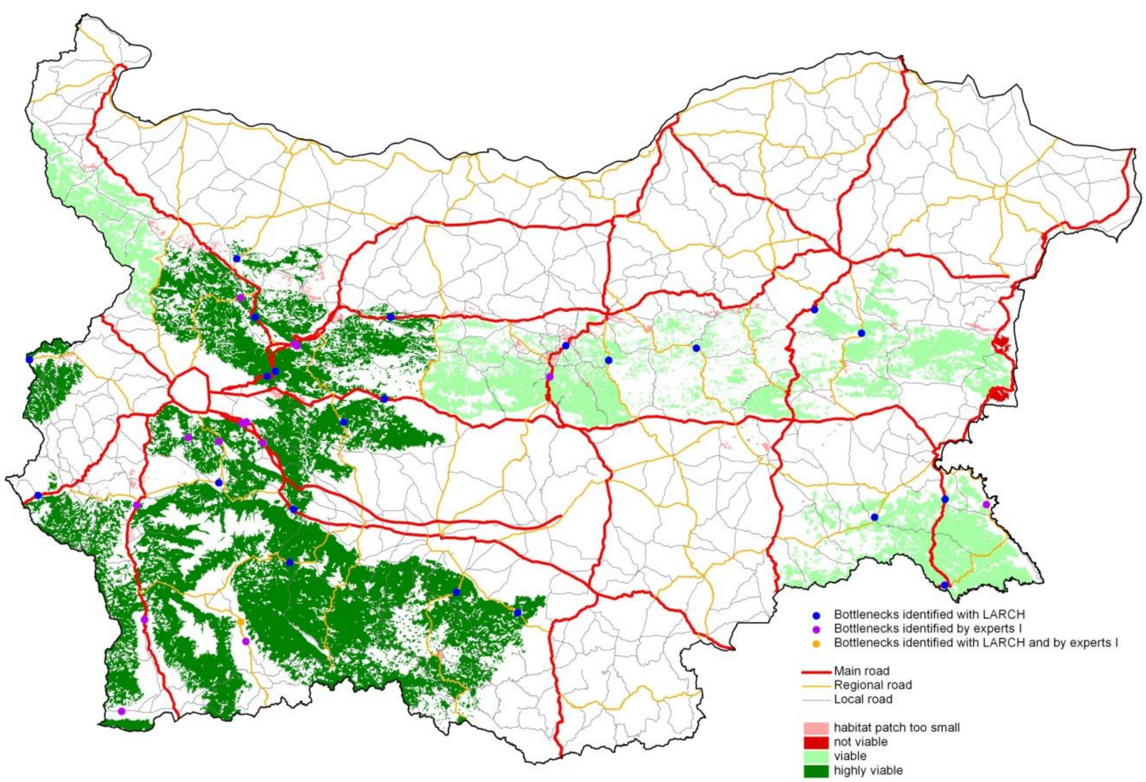
Before: The "before" situation: population viability of pine marten in Bulgaria in the current situation without de-fragmentation measures in the road and railroad network.



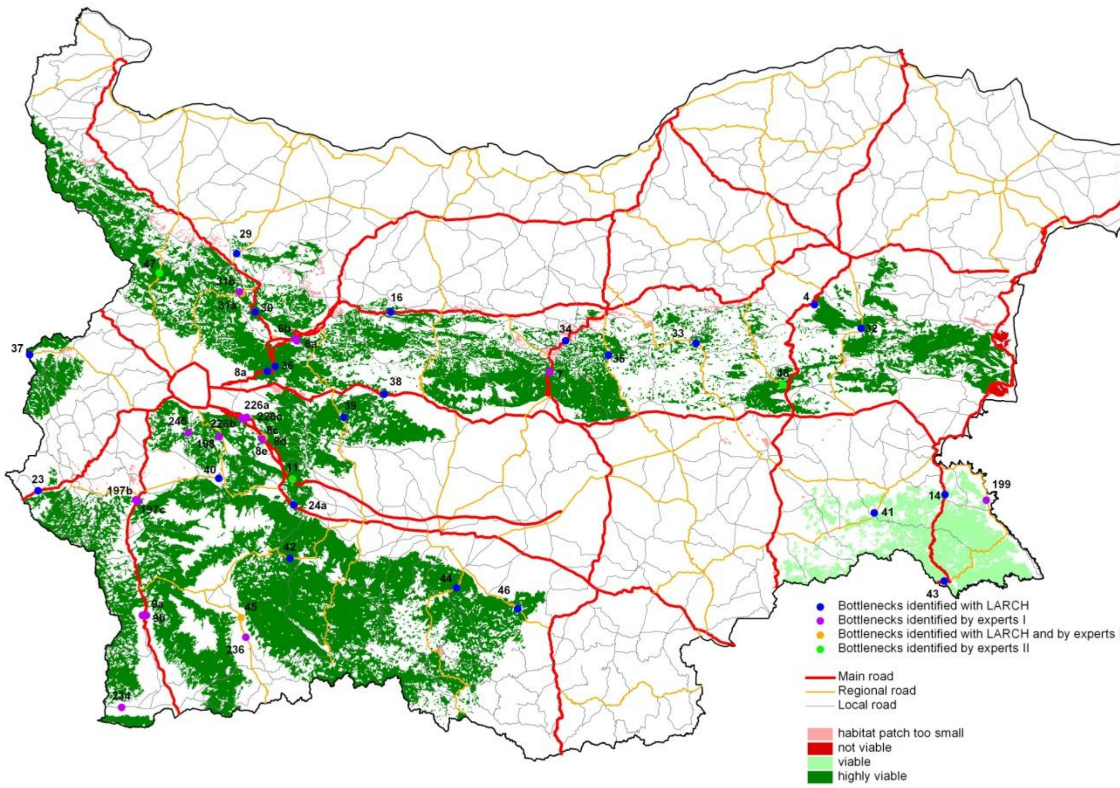
Step 1: Bottleneck locations identified with the LARCH model for the pine marten and the population viability of the species when de-fragmentation measures will be taken at these locations.



Step 2: Bottleneck locations identified by species experts for the pine marten and population viability of the species when de-fragmentation measures will be taken at these locations.



Step 3: Integration of bottleneck locations identified with the LARCH model and by species experts for the pine marten and population viability of the species when de-fragmentation measures will be taken at all these locations.



Step 4: Identification of additional spots for de-fragmentation where measures will improve the viability of the population significantly (light green spots) and population viability of the pine marten when de-fragmentation measures will be taken at all identified locations.

Figure 1. The four steps to identify bottleneck locations in the Bulgarian road and railroad network illustrated for pine marten.

Setting Priorities

The study identifies a large number of bottleneck locations and this raises the question of where to begin? What bottleneck locations should most urgently be addressed? Which locations might be addressed later? In this study we distinguished *low*, *medium* and *high* priority locations. These definitions are based upon (1) the ecological benefit classes given by the LARCH model, (2) the urgency classes given by the species experts, and (3) the amount of sustainable habitat for a species in the present situation (see also Table 2).

LARCH categorized each identified bottleneck location into one of five ecological benefit classes (see also Van der Grift & Pouwels 2006). Classes 1, 2 and 3 refer to bottleneck locations with *immediate* shifts in population viability due to de-fragmentation measures in relatively large, medium-sized and small populations, respectively. Classes 4 and 5 refer to bottleneck locations with *secondary* shifts in population viability due to de-fragmentation measures, i.e. shifts that only occur when de-fragmentation measures are initially taken elsewhere. Class 4 refers to secondary shifts of viable into highly viable populations. Class 5 refers to secondary shifts of non-viable into viable or highly viable populations. The species experts categorized each identified bottleneck location into one of two classes of urgency: *highly urgent* and *less urgent*. The need for de-fragmentation measures is less when, under the present situation most habitat is estimated to support already highly viable populations. In setting priorities we differentiate between species that currently have more or less than 75% of their habitat supporting highly viable populations, since we expect that for species with >75% of their habitat supporting highly viable populations, sufficient measures can be planned at a later stage if conditions deteriorate due to road impacts.

If a bottleneck location was identified for just one of the indicator species, the location was given the priority class as was assessed for that particular species. If a bottleneck location was identified for more than one indicator species, the location was given the highest assessed priority class in this group of species.

= High priority
= Medium priority
= Low priority

		LARCH ecological benefit class					
		Class 1 Viability shift in large population	Class 2 Viability shift in medium-sized population	Class3 Viability shift in small population	Class 4 Shift from viable to highly viable	Class 5 Shift from non-viable to viable or highly viable	None[2]
		Immediate benefit			Secondary benefit		
Species for which, at present, <75% of the habitat supports highly viable populations *Brown bear, Wolf, Wildcat, Pine marten, Otter*							
Expert urgency class	High urgency						(c)
	Low urgency						(c)
	None[1]	(a)	(a)	(a)	(a)	(a)	(b)
Species for which, at present, ≥75% of the habitat supports highly viable populations *Red deer, Souslik, Aesculapian snake, Blotched snake, Tortoises, Common toad*							
Expert urgency class	High urgency						(c)
	Low urgency						(c)
	None[1]	(a)	(a)	(a)	(a)	(a)	(b)

1 Bottleneck locations only identified with the LARCH model (a) or identified during the optimization step (b).
2 Bottleneck locations only identified by species experts (c) or identified during the optimization step (b).

Table 2. Set of rules used to identify *low*, *medium* and *high* priority locations for road and railroad mitigation.

Quick-scan of Needed Mitigation Measures

For each identified bottleneck location we explored what measures will be needed to solve the problems of barrier effect and road-kill for wildlife. To do so each bottleneck location was visited and the best set of measures was determined. Choices for measures were primarily based on the preferences of the indicator species for different types of measures, the characteristics of the road/railroad and traffic, the presence of existing crossing structures, such as bridges or culverts, and the configuration of wildlife habitat around the identified problem section. This approach can be best described as a "quick-scan"; hence the mitigations suggested here should be seen as not more than a first proposal for a more detailed de-fragmentation program.

Results

Bottleneck Locations

In total 283 bottleneck locations were identified in the existing road and railroad network of Bulgaria (Figure 2). These bottlenecks were almost equally divided between main roads and regional roads; 130 and 125 respectively. Far fewer bottlenecks were identified on local roads and railroads: 10 and 18 respectively. Although mapped as single spots on the map, each bottleneck location indicates a section of road or railroad that forms a barrier between wildlife populations of one or more indicator species on either side of the transport corridor. Hence the dots on the map do not represent the exact location where wildlife crossing structures should be established, but are merely the starting point for identifying the most appropriate locations for de-fragmentation measures.

At some bottleneck locations de-fragmentation measures will only have the desired effect on population viability if other spots are addressed simultaneously. For example, this may be the case when two roads/railroads have to be crossed to restore the desired connectivity between wildlife populations. If both are considered as barriers for one or more of the indicator species, mitigation measures at just one of them would not be very effective. A positive shift in viability can then only be obtained if wildlife-crossing structures are established at both barriers. In such cases we speak of "associated bottlenecks". In most cases a group of associated bottlenecks consists of just two locations that are close together on parallel roads or railroads. However, in six cases a group of associated bottlenecks contains more than two locations. In these associated bottlenecks each bottleneck has been given the same number, but each with a different extension (-a, -b, -c, etc). In total 24 groups of associated bottlenecks were identified.

A little more than half of all identified bottlenecks relate to two or more indicator species (Figure 3). A few locations have been identified as bottlenecks for 10 species. At locations identified as bottlenecks for several species the construction of multi-species wildlife passages, such as wildlife overpasses, can be very effective as a high number of indicator species will benefit from the measure, as well as all those species for which the indicator species are indicative. These locations are also the most likely places where a combination of different types of mitigation measures should be applied, as different species inhabit different habitats along the road section and different mitigation measures will be appropriate for each species.

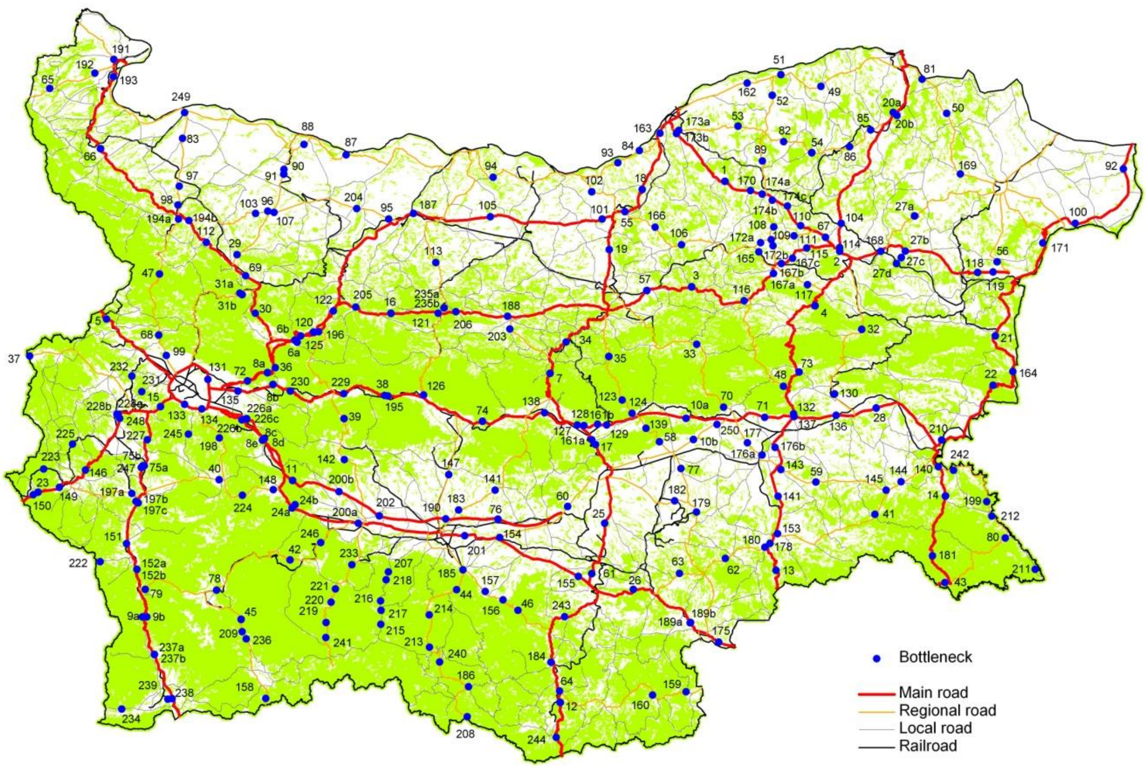


Figure 2. Identified bottleneck locations in the Bulgarian road and railroad network.

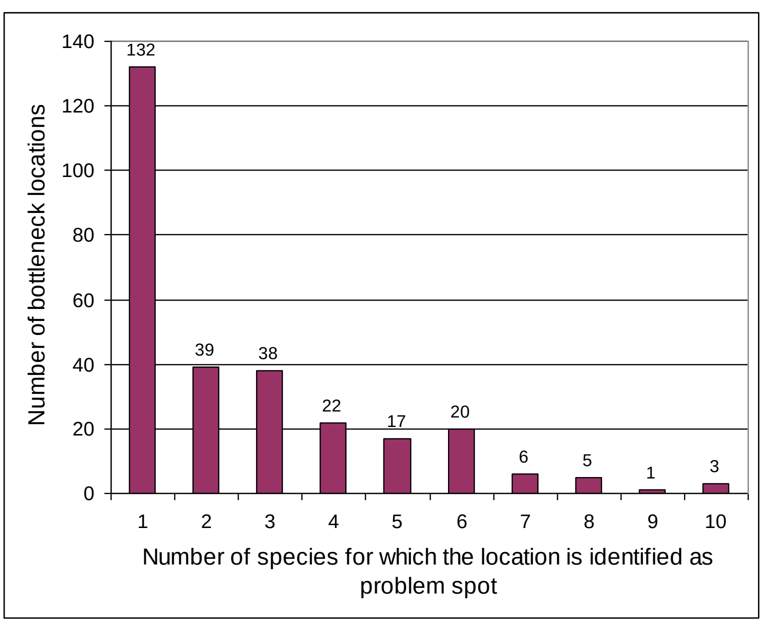


Figure 3. Distribution of the identified bottleneck locations in the Bulgarian road and railroad network over the number of indicator species for which a location is identified as problem spot.

Priorities

The identification of a total of 283 bottlenecks leads to an assessment of the locations where mitigation measures are most urgently needed. Figure 4 shows the priority class for each identified bottleneck, based on the expected increase in the viability of populations and expected decrease in wildlife mortality due to collisions in traffic after mitigation. About 30% of all bottlenecks are classified as *high priority* locations (Figure 5). Immediate action is recommended at these locations as these have been identified as locations where the barrier effect of the road or railroad is high and/or wildlife is frequently killed in traffic.

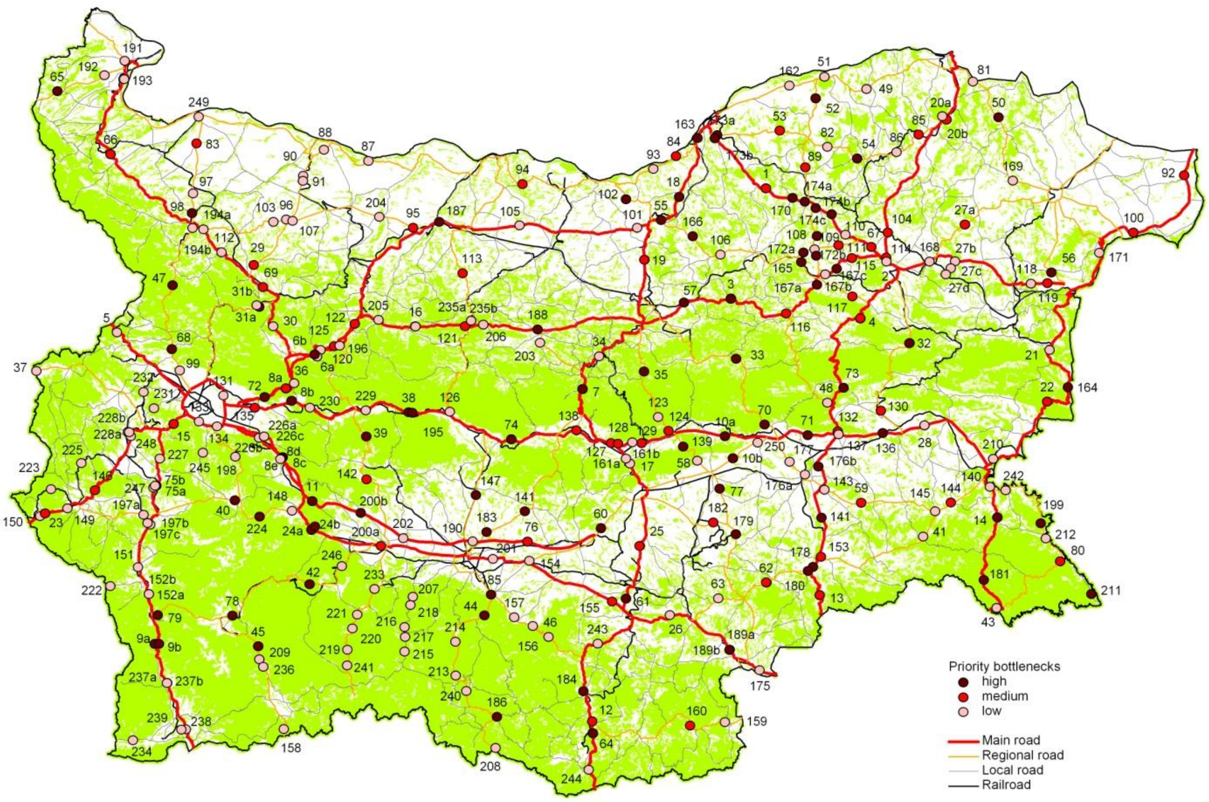


Figure 4. Priority class for each of the identified bottleneck location.

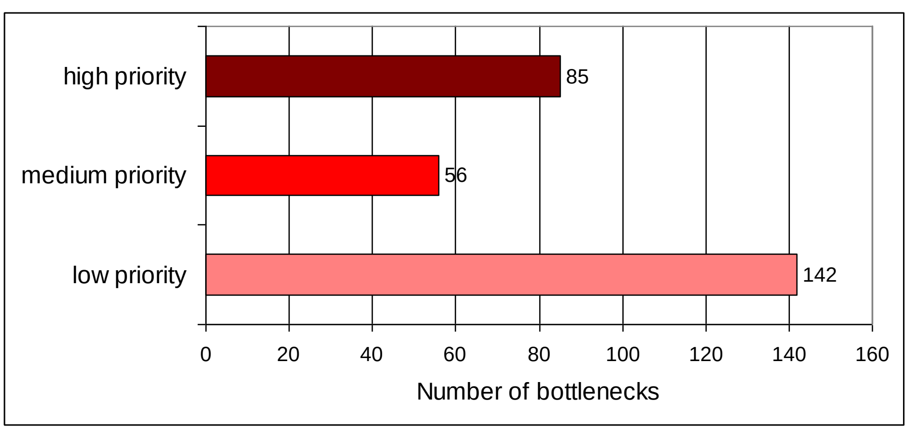


Figure 5. Distribution of bottleneck locations over priority classes. High priority = mitigation measures should be taken before 2015; Medium priority = mitigation measures should be taken before 2020; Low priority = mitigation measures should be taken before 2025.

Improvement Population Viability Indicator Species

For brown bear 67 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 3 were identified by the LARCH model, 56 by species experts and 8 by both the model and the species experts. At present about 40% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift almost all *not viable* and *viable* populations towards *highly viable* populations. Most bottleneck locations for brown bears are found in the central and southwestern parts of Bulgaria. De-fragmentation initiatives for brown bear are of the highest importance at bottleneck locations in the Struma River valley, on the roads and railroads between the Central Balkan and the Rila mountain ranges, and on the roads between Vitosha and Rila. Furthermore, significant shifts in population viability can be reached through road mitigation at transport corridors between the Western and Eastern Rhodopes, on the main road between the eastern and western parts of the Central Balkan range and on main roads that crosses the Central Balkan, just east of Sofia. At most other locations de-fragmentation measures would primarily reduce road-kills of brown bear and strengthen habitat connectivity within their current distribution area.

For wolf 80 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 8 were identified by the LARCH model, 63 by species experts, and 7 by both the model and species experts. Two bottleneck locations were added to restore habitat connectivity between the Eastern Rhodopes and Strandja. In the current situation about 25% of all populations can be categorized as *highly viable*. As a result of de-fragmentation measures at the identified bottleneck locations all *not viable* and *viable* populations are expected to shift towards *highly viable* populations. Most bottleneck locations for wolf are found in the central and southwestern parts of Bulgaria. De-fragmentation initiatives for wolf are of highest importance at bottleneck locations in the Struma River valley, on the roads and railroads between the Central Balkan and the Rila mountain ranges, on the roads between Vitosha and Rila, and between the Eastern Rhodopes and the southeastern parts of the country. Furthermore, significant shifts in population viability can be reached through road mitigation along transport corridors between the Western and Eastern Rhodopes, on the main road between the eastern and western parts of the Central Balkan range and on main roads in the northeast of the country. At most other locations de-fragmentation measures would primarily reduce road-kills of wolf and strengthen habitat connectivity within their current distribution area.

For red deer 71 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 8 were identified by the LARCH model, 60 were identified by species experts and 3 by both the model and by species experts. Currently more than 75% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations would lead almost all *not viable* and *viable* populations to shift towards *highly viable* populations. Most bottleneck locations for red deer are found in the western parts of Bulgaria. There are some bottleneck locations in the eastern part of the country, although far fewer. De-fragmentation initiatives for red deer are of highest importance at bottleneck locations in the Struma River valley, on the roads and railroads between the Central Balkan and the Rila mountain range, on the roads between Vitosha and Rila, and on the roads in the mainly agricultural landscape with scattered forests in northern Bulgaria. At most other locations de-fragmentation measures would primarily reduce road-kills of red deer and strengthen habitat connectivity within their current distribution area. Since more than 75% of all red deer populations are already highly viable no bottlenecks were categorized as *high priority*.

For wildcat 52 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 14 were identified by the LARCH model, 25 were identified by species experts, and 6 by both model and species experts. Seven bottleneck locations were added to restore habitat connectivity between the Central Balkan and Rila mountain ranges, within Strandja and between scattered wildcat habitat patches in northeastern Bulgaria. Presently no populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift almost all the *not viable* and *viable* populations towards *highly viable* populations. Most bottleneck locations for wildcat are found in the western parts of Bulgaria, with far fewer bottleneck locations in the eastern part of the country. De-fragmentation initiatives for wildcat are of highest importance at bottleneck locations in the Struma River valley, on the roads and railroads between the Central Balkan and the Rila mountain ranges, on the road between the eastern and western parts of the Central Balkan range, and on the coastal road along the Black Sea in Strandja. At most other locations de-fragmentation measures would primarily reduce road-kills of wildcat and strengthen habitat connectivity within their current distribution area.

For pine marten 46 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 25 were identified by the LARCH model, 14 were identified by species experts, and 4 by both model and species experts. Three bottleneck locations were added to restore habitat connectivity between the pine marten habitats in the most western parts of the Central Balkan range, between the most eastern parts of the Central Balkan range and the pine marten habitats along the Black Sea coast, and between the Central Balkan Range and the Rila mountains. In the current situation less than 25% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift most *not viable* and *viable* populations towards *highly viable* populations. Most bottleneck locations for pine marten are found in the central and western parts of Bulgaria and in Strandja. De-fragmentation initiatives for pine marten are of highest importance at bottleneck locations in the Struma River valley, on the roads and railroads between the Central Balkan and the Rila mountain range, on the roads between Vitosha and Rila, on the roads between Rila/Pirin and the Western Rhodopes, and on the coastal and inland roads in Strandja. At most other locations de-fragmentation measures would primarily reduce road-kills of pine marten and strengthen habitat connectivity within their current distribution area.

For otter 110 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 75 were identified by the LARCH model, 21 were identified by species experts, and 10 by both model and species experts. Four bottleneck locations were added to restore habitat connectivity in river tributaries in northeastern Bulgaria. In the current situation about 25% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift all *not viable* and *viable* populations towards *highly viable* populations. Bottleneck locations for otter are found in all parts of Bulgaria as, in all regions, important river habitats are frequently crossed by roads and railroads. De-fragmentation initiatives for otter are of highest importance at bottleneck locations in the Struma and Maritza River valleys, on the roads between the Western and Eastern Rhodopes, in Strandja, along the Black Sea coast and around Shoumen in the northeast. At most other locations de-fragmentation measures would primarily reduce road-kills of otter and strengthen habitat connectivity within their current distribution area.

For marbled polecat 61 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 34 were identified by the LARCH model, 19 were identified by species experts and 6 by both model and species experts. Two bottleneck locations were added to restore habitat connectivity in the region north of Shoumen. At present about 65% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift most *not viable* and *viable* populations towards *highly viable* populations. Bottleneck locations for marbled polecat are found in all parts of the country with the exception of the high mountain regions and the Danube lowlands around Pleven. De-fragmentation initiatives for marbled polecat are of highest importance at almost half of all bottleneck locations, including bottlenecks in the Struma River valley, around the Pirin mountains, in the foothills of the Central Balkan mountain range, in Strandja and in the grassland areas of the northeast. At most other locations de-fragmentation measures would primarily reduce road-kills of marbled polecat and strengthen habitat connectivity within their current distribution area.

For souslik 125 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 109 were identified by the LARCH model, 11 were identified by species experts, and 5 by both model and species experts. In the current situation over 80% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to lead to only a slight increase in *highly viable* populations. Bottleneck locations for souslik are found in all parts of the country with the exception of the high mountain regions. De-fragmentation initiatives for souslik are of considerable importance at almost half of all these bottleneck locations, including bottlenecks in the Struma River valley, in the foothills of the Central Balkan mountain range, in Strandja and in the grassland areas around Shoumen. Because more than 75% of all souslik populations are already *highly viable* in the current situation no bottlenecks were categorized as *high priority*.

For aesculapian snake 22 bottlenecks have been identified in the current road and railroad network in Bulgaria. All of these were identified by the species experts. Currently more than 95% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations will not do much to change population viability, but road-kill of these snakes is expected to reduce significantly. Most bottleneck locations for aesculapian snake are found in the southeastern parts of Bulgaria. De-fragmentation initiatives for aesculapian snake are of considerable importance at bottleneck locations in the Struma River valley, in Eastern Rhodopes, in Strandja and along the central Black Sea coast. Because more than 75% of all aesculapian snake populations are already *highly viable* in the current situation no bottlenecks were categorized as *high priority*.

For blotched snake 39 bottlenecks have been identified in the current road and railroad network in Bulgaria. Of these, 22 were identified by the LARCH model, 14 were identified by species experts, and 3 by both model and species experts. In the current situation almost 80% of all populations can be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are expected to shift most *not viable* and *viable* populations towards *highly viable* populations. Most bottleneck locations for blotched snake are found in the eastern parts of Bulgaria. De-fragmentation initiatives for blotched snake are of considerable importance at about one-third of all bottleneck locations, including those in Eastern Rhodopes, Strandja, along the Black Sea coast and in the region north of Shoumen. Because more than 75% of all blotched snake populations are already *highly viable* no bottlenecks were categorized as *high priority*.

For Hermann’s tortoise and spur-thighed tortoise 29 bottlenecks have been identified in the current road and railroad network in Bulgaria. All of these were identified by the species experts. At present more than 90% of all populations can already be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations will not do much to change population viability but is expected to significantly reduce road-kills of tortoises. Most bottleneck locations for tortoises are found in the southwestern and southeastern parts of Bulgaria. De-fragmentation initiatives for tortoises are of considerable importance at bottleneck locations in the Struma River valley and along the Black Sea coast. Because more than 75% of all tortoise populations are already *highly viable* no bottlenecks were categorized as *high priority*.

For common toad 29 bottlenecks have been identified in the current road and railroad network in Bulgaria. All of these were identified by the species experts. Currently more than 95% of all populations can already be categorized as *highly viable*. De-fragmentation measures at the identified bottleneck locations are not expected to do much to change population viability, but can be expected to significantly reduce road-kills of common toads. Most bottleneck locations for common toads are found in the Struma River valley, in Eastern Rhodopes and along the Black Sea coast in Strandja. Because more than 75% of all common toad populations are already *highly viable* no bottlenecks were categorized as *high priority*.

Figure 6 shows the expected shift in population viability of each indicator species due to proposed road and railroad mitigation. Population viability in the bar ‘maximum’ refers to the viability of the populations in the hypothetical case of no roads or railroads existing, i.e. if the barrier effect of all roads and railroads is completely removed and where the population viability is solely dependant on the size, quality and configuration of the habitat network. This ‘maximum’ estimation can be seen as the maximum possible population viability achievable solely through de-fragmentation measures in the road and railroad networks. Further improvements of population viability, if any, can only be reached through measures other than road mitigation, such as habitat enlargement, improvements or establishing ecological corridors between habitat patches.

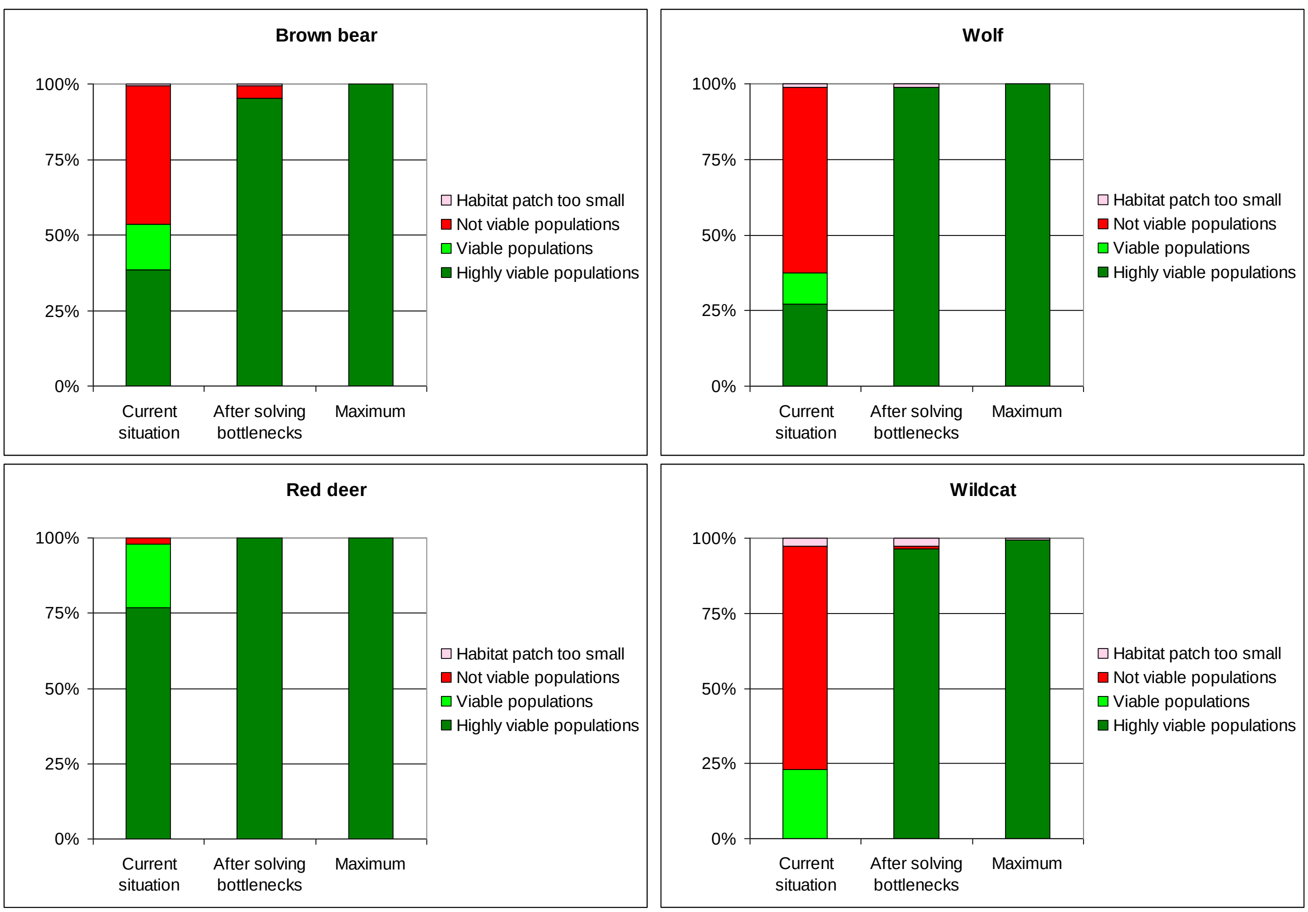
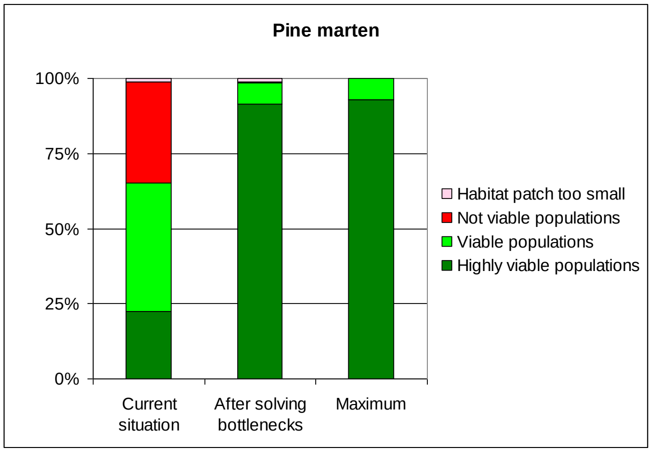
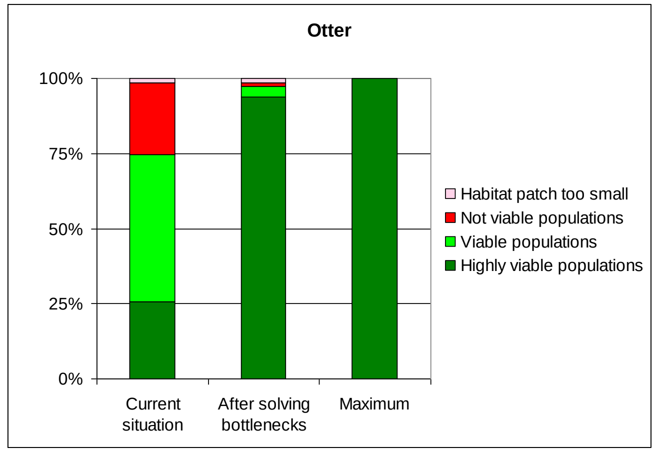
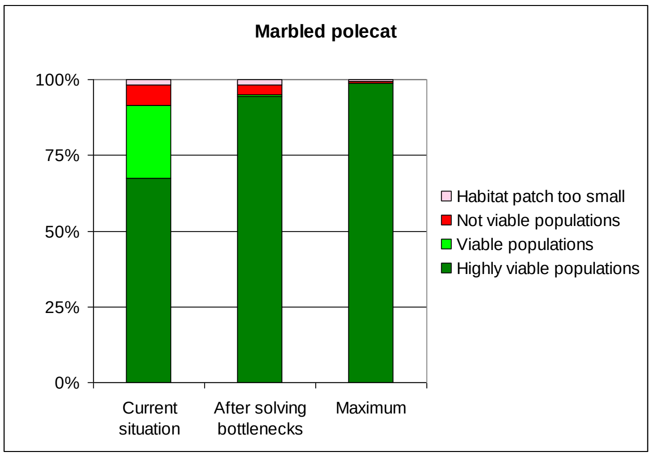
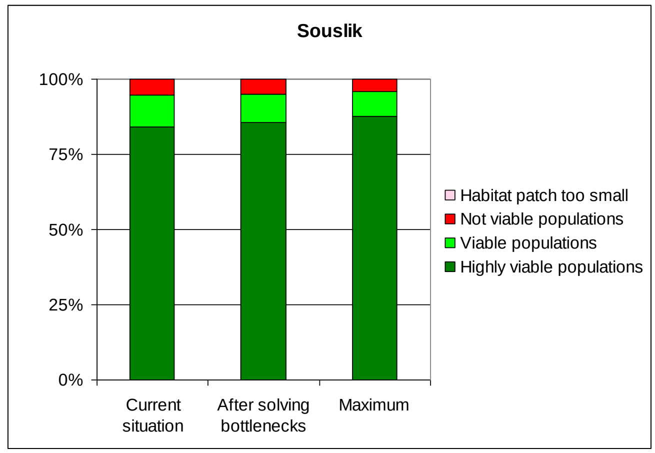


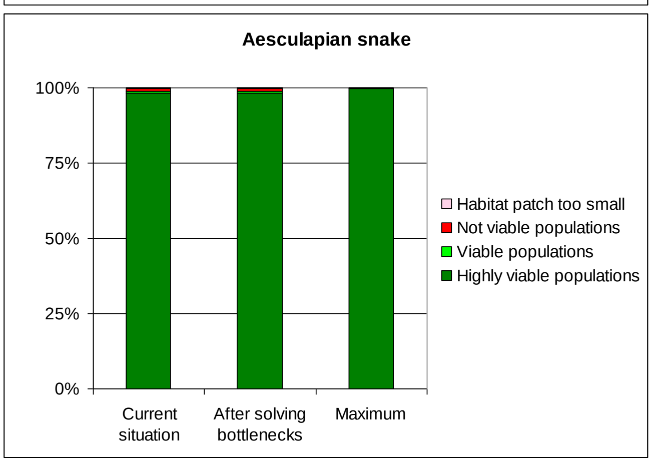
Figure 6. Shift in population viability of each indicator species due to proposed road and railroad mitigation.
(Figure continued on next page.)

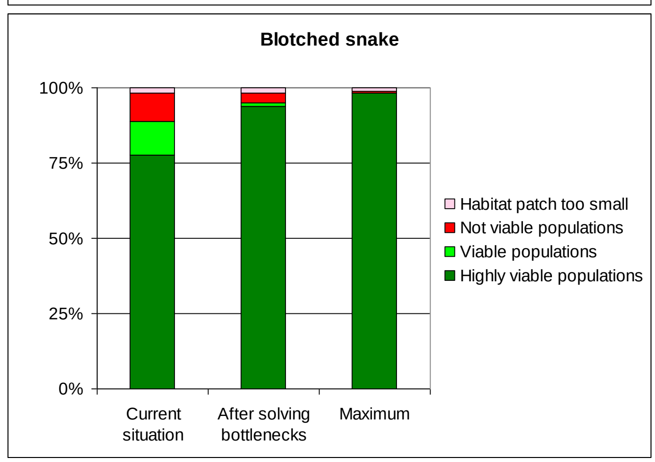

Pine marten
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations

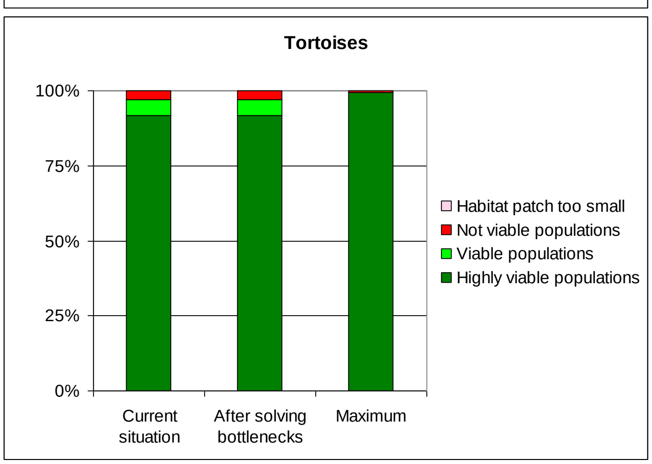

Otter
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations

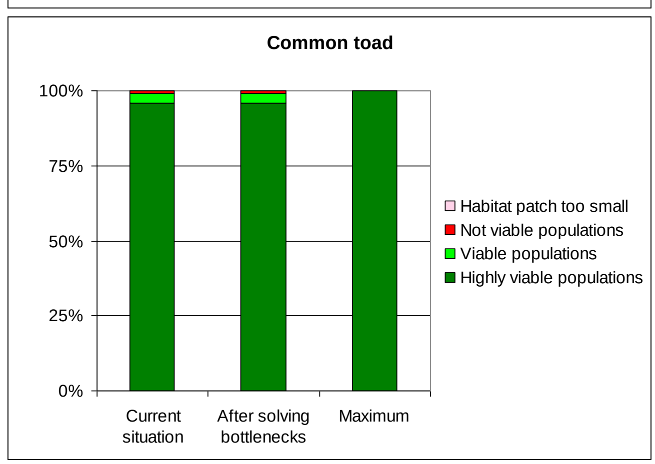

Marbled polecat
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations


Souslik
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations


Aesculapian snake
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations


Blotched snake
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations


Tortoises
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations


Common toad
100%
75%
50%
25%
0%
Current situation
After solving bottlenecks
Maximum
Habitat patch too small
Not viable populations
Viable populations
Highly viable populations

Mitigation Measures

In total 544 mitigation measures were identified as necessary to restore habitat connectivity and reduce wildlife mortality at all bottleneck locations. This number exceeds the number of bottleneck locations, as at 30% of all bottleneck locations more than one measure is needed to solve the problems. A significant number (331) of these proposed mitigation measures involve adapting existing structures, such as road tunnels, viaducts or bridges, to allow for better use of these structures by wildlife. In addition the construction of 213 wildlife passages is needed, which will be exclusively for the use by wildlife (Figure 7). The construction costs of all proposed de-fragmentation measures are estimated at 132 million Euros (Van der Grift et al. 2008). If the recommended timetable for implementing the plan is used – all measures taken before 2025 – the average yearly costs will be less than 10 million Euros. These costs do not include the costs for planning and designing the measures, nor do they include the costs for purchasing land if any additional (non-governmental) land is needed to allow for proper habitat development and management in "buffer-zones" around the entrances of the wildlife passages.

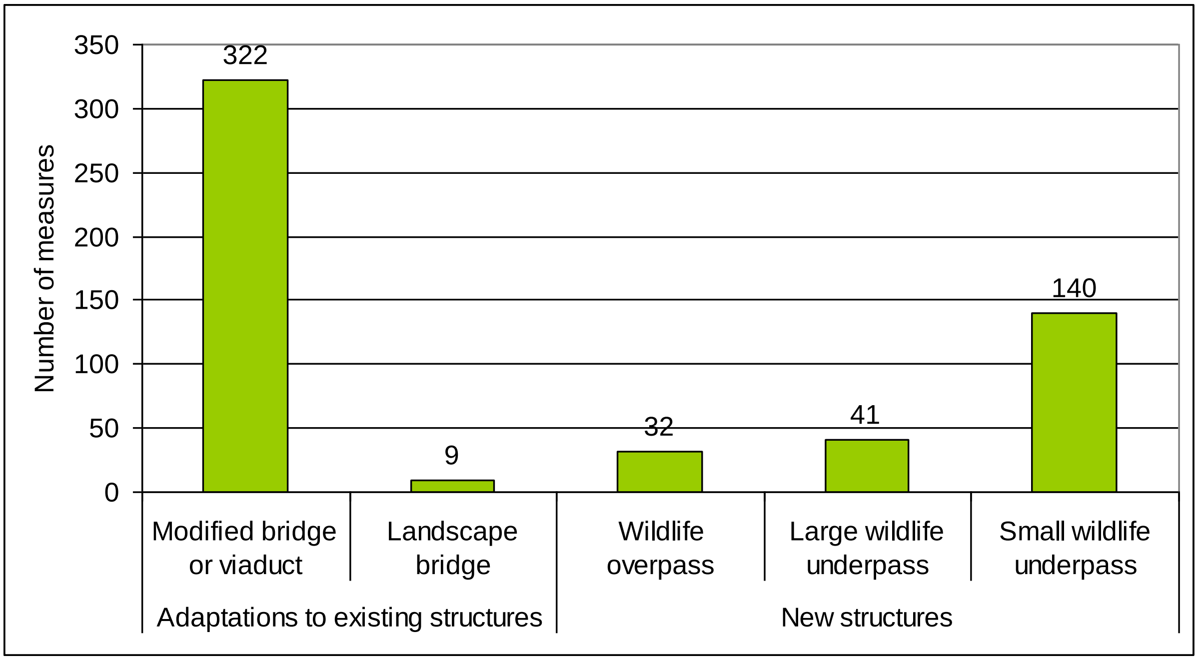


Figure 7. Number of proposed mitigation measures for each type of measure.

<u>Next Steps</u>

The implementation of the here proposed road and railroad mitigation is expected to significantly improve the population viability of most threatened wildlife species and, as such, is an indispensable first step in preserving Bulgaria's biodiversity and developing a coherent and sustainable ecological network across the country. In 2008 an interdepartmental agreement between all governmental authorities involved in road development, spatial planning and biodiversity conservation was signed in order to express their support and commitment for the development and implementation of a national policy plan for habitat defragmentation across transportation corridors in Bulgaria. A few actions are recommended to create functional ecological corridors in Bulgaria, solve current bottlenecks in the road and railroad network and prevent future fragmentation of nature areas by transport infrastructure: (1) Appoint a taskforce for the De-fragmentation of Transportation Corridors in Bulgaria, with representatives from all relevant ministries, stakeholders, NGOs and scientists. The taskforce initiates the compilation of a national de-fragmentation program and its implementation. (2) Appoint a national coordinator for de-fragmentation measures in the road and railroad network, responsible for coordinating all actions carried out by the taskforce and communication with the general public. (3) Work out a national de-fragmentation program with political approval and secure the required budget. (4) Compile a handbook that provides guidelines for the planning, design and construction of effective wildlife passages. This should draw on experiences and best practice elsewhere in Europe. (5) Set up an implementation plan in which the planning and procedure for each de-fragmentation location is worked out. Gear the implementation plan to the planning of road construction/upgrading projects. Choose a regional planning approach in order to coordinate measures at adjacent infrastructural barriers. (6) Choose one or two pilot projects to work out an efficient way to plan and construct de-fragmentation measures, to allow Bulgarian experts to gain knowledge and experience, and to raise awareness among the general public over the issue of habitat fragmentation and the need to restore ecological networks. (7) Incorporate the maintenance of established de-fragmentation measures in current road management procedures and arrange for proper nature management of surrounding areas in compliance with the preferred conditions for an effective wildlife corridor. (8) Set up a monitoring program to evaluate whether de-fragmentation measures function properly and whether conservation objectives are achieved.

Biographical Sketches

Edgar van der Grift works as a senior research scientist at Alterra, Wageningen University and Research Institute, Wageningen, The Netherlands. His work focuses on the assessment of the impacts of habitat fragmentation on wildlife populations and the effectiveness of measures that aim to reduce such fragmentation and increase habitat connectivity, e.g. the establishment of landscape linkages, ecological corridors and wildlife crossing structures at roads and railroads. Besides his scientific research he acts as a consultant for policy makers, road planners and conservation groups during the preparation and implementation phase of projects that aim for the establishment of effective ecological networks and road mitigation measures.

Valko Biserkov is director of the Central Laboratory of General Ecology of the Bulgarian Academy of Sciences in Sofia, Bulgaria. He studied the distribution and ecology of amphibians and reptiles in the Balkan. His current work focuses on the development of ecological network such as the establishment of a NATURA2000 network in Bulgaria. Furthermore he is involved in the planning of defragmentation measures at existing and new motorways across Bulgaria.

Vanya Simeonova is a research scientist at Alterra, Wageningen University and Research Institute, Wageningen, The Netherlands. She works on environmental policy integration in urban and suburban areas as well as regional development studies in Eastern European countries. Furthermore she is involved in studies on the implementation of ecological networks and the optimization of planning processes for such networks.

Marcel Huijser received his M.S. in population ecology and his Ph.D. in road ecology at Wageningen University in Wageningen, The Netherlands. He studied plant-herbivore interactions in wetlands for the Dutch Ministry of Transport, Public Works and Water Management, hedgehog traffic victims and mitigation strategies in an anthropogenic landscape for the Dutch Society for the Study and Conservation of Mammals, and multifunctional land use issues on agricultural lands for the Research Institute for Animal Husbandry at Wageningen University and Research Center. Currently he works on wildlife-transportation issues for the Western Transportation Institute at Montana State University. He is a member of the Transportation Research Board (TRB) Committee on Ecology and Transportation and co-chairs the TRB Subcommittee on Animal-Vehicle Collisions.

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