LIFE SAFE-CROSSING

PREVENTING ANIMAL-VEHICLE COLLISIONS

LIFE17 NAT/IT/000464

ACTION A3. Assessment on road traffic accidents and large carnivore core areas affected by roads

December 2019

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Responsible partner: MINUARTIA

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1. Introduction

1.1 General presentation and aims of the action

The objective of this action is to provide information on the impact of road mortality on large carnivores species: Brown bear, Marsican brown bear, Iberian lynx and wolf (referred as 'target species') and to analyse movements of bears in relation to roads, in different study areas on the basis of data provided by the project partners.

The action is preparatory for the C action. The information collected will be used to assess decision process about location of mitigation measures to be undertaken (Action A.4 and Action A.5).

The action provides information on the extent and distribution of road traffic accidents involving large carnivores and other wild species in each study area. This data provides the baseline situation, before the application of mitigation measures and will allow to evaluate the effectiveness of the actions, by comparing the situation before and after undertaking the measures (D actions).

Accordingly, **the main aim of the action is to assist the decision-making process to select road stretches where mitigation actions need to be implemented to prevent road mortality on large carnivore**, as well as on other mammal species.

The specific objectives of the task are:

- **To identify AVC clusters along roads located in the study areas**. This analysis is based on data of Animal-Vehicle Collisions (AVC) and aims to determine which are the sections with higher road mortality risks for the project target species.

- **To identify the areas beside roads which are more intensively used by the project target species**, as well as to identify the road sections where clusters of road crossing points have been detected. These analyses are based on telemetry data of a set of monitored individuals and provide complementary data to be used in the selection of road sections where mitigation measures are going to be applied.

These activities are common to all project areas, but some differences are related to the different data set available in terms of total numbers of road collisions involving target species, the way they were collected and stored, as well as the available telemetry data.

In the different project areas, a standardized analysis applying KDE+ software has been undertaken. This method designed by the Czech Transport Research Centre (CDV) has previously been tested with data from several European Countries in the framework of the project 'Safe Roads for Wildlife and People' developed by the CEDR (European Conference of General Directors of Roads), and in many other study areas from all over Europe. The application of a common methodology guarantees that all data is analysed applying the same procedures and it assures the reliability of analyses.

Results will provide valuable knowledge and data for other regions with similar problems, and it will offer a methodological approach which can be applied to facilitate the process of selecting road sections in which to implement mitigation measures to prevent wildlife collisions.

The present report includes the description of the above-mentioned methodology and, for each study area, results on the identification of the most conflictive road stretches where high number of target species crossings are expected to occur based on registered movements and road collisions data.

1.2 Project study areas

Action A3 is developed in the four countries participating in the project which are listed below (see Figure 1):

- **Greece**
  Study area: Kastoria and Florina provinces (identified as 'GR Kastoria - Florina').
  Project target species: Brown bear.
  Project partners: CALLISTO; EGNATIA ODOS.

- **Italy**
  Two project partners have provided information of two different areas.

  Study area: Abruzzo, Lazio and Molise National Park (identified as 'IT PNALM').
  Project target species: Marsican brown bear.
  Project partners: PNALM.

  Study area: Majella National Park (identified as 'IT PNMajella').
  Project target species: Marsican brown bear.
  Project partners: PNM.

- **Romania**
  Study area: Curbura Carpatilor (SE Carpathians; identified as 'RO Curbura Carpatilor).
  Project target species: Brown bear.
  Project partners: MARIN DRĂCEA.

- **Spain**
  Study areas: Doñana National Park and Sierra Morena (identified as 'ES Doñana - Sierra Morena').
  Project target species: Iberian lynx.
  Project partners: JUNTA DE ANDALUCÍA.

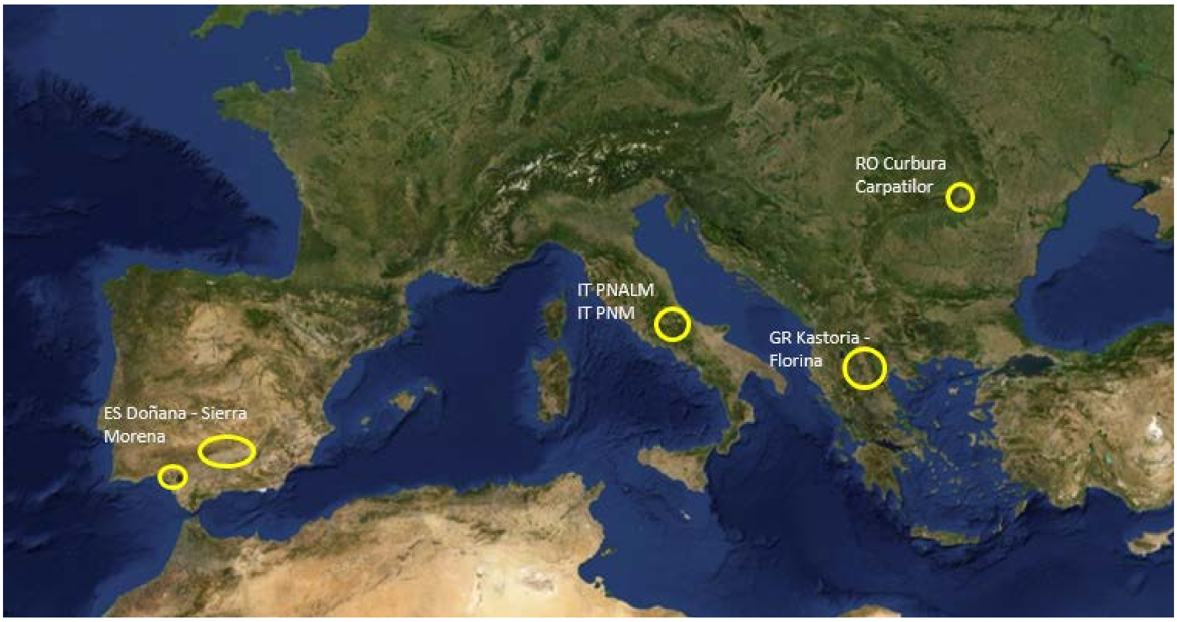

Figure 1. Location of study areas.

2. Methods

2.1 Data

a) Data gathered

AVC and telemetry data were collected from historical registers and several project databases:

- **Greece**
  - Highway companies (Egnatia Odos S.A.)
  - NGOs (CALLISTO Wildlife and Nature Conservation Society)
  - LIFE ARCTOS/KASTORIA project
  - LIFE AmyBear project

- **Italy**
  - Park Administrations
  - Province Administrations and Regions
  - LIFE STRADE project
  - iNaturalist
  - Ornitho

- **Romania**
  - LIFE FOR BEAR project

- **Spain**
  - Andalusian Regional Ministry of Infrastructures
  - LIFE+ IBERLINCE project

AVC data provided ranged from years 1975 to 2019, and telemetry data from years 2005 to 2018, with different recording periods between study areas (see Figure 2 and 3).

b) Data used in the analysis

A common GIS layer including all AVC records, provided by all project partners, were created. Data were converted from various Coordinate Representation System to a common one, names and parameter encoding were also unified. Only large carnivore, other wild carnivore and ungulate species were included in the analysis. Other species including domestic animals, rodents (squirrels), insectivores (hedgehogs), reptiles, birds and 'unknown species' were not included. American mink was also not included due that it is an invasive alien species that could come from escaped individuals of captivity (fur farms) and is only associated to aquatic habitats. Obvious errors or duplicates were also deleted (see Table 1).

AVC data used in the analysis consisted in 515 collisions with wildlife (see Figure 2 and Table 1): 249 AVC involved target species (78 brown bear, 6 Marsican brown bear, 45 wolf, 120 Iberian lynx); 196 wild ungulates (82 wild boar, 66 red deer and 48 roe deer) and 70 other wild carnivores (22 fox, 30 badger, 12 wild cat, 6 marten).

Data from non-target species was included in the analysis considering them as indicators of potential corridors across the road. Inclusion of these registers also helped to enhance the power of clustering identification by providing larger sample sets.

Telemetry data used in the analysis consisted in a database of 79 radio collared brown bears (see Figure 3 and Table 2.): 32 tracked in Romania, 23 in Greece and 24 in Italy (23 Marsican brown bears in PNALM and 1 in PNM). Data distributed along a time period of 14 years, from 2005 to 2019.

Data from Iberian lynx monitored in the Spanish areas (Doñana and Sierra Morena) have not been included in the analyses as a previous study promoted by the project partner Junta de Andalucía already provided the information about core areas and main ecological corridors used by the species in the framework of LIFE+ IBERLINCE project (see paper by Illanas et al., 2017). This study provides the information needed for the assessment of road sections where mitigation measures are going to be implemented.

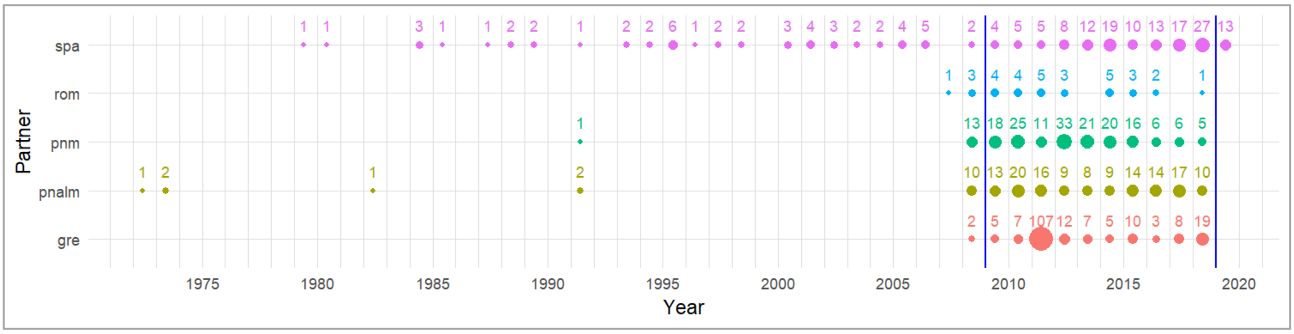

Figure 2. Time range of the AVC data collected (target species, other wild carnivore and ungulate). Only registers comprised in the decade of 2009 to 2018 was used for the AVC cluster analysis.

Figure 3. Time range of telemetry data (brown bear and Marsican brown bear) collected and used in the analysis.

Table 1. AVC data with location coordinates gathered from each study area and final set of data included in the analysis.

AVC data										**Included in the analysis**						
Study areas	**Target species**		**Ungulate species**		**Wild carnivore species**		**Other species**		**Total**	**Target species**		**Ungulate species**		**Wild carnivore species**		**Total**
GR Kastoria-Florina [1]	**Total**	**59**	**Total**	**0**	**Total**	**27**	**Total**	**99**	**185**	**Total**	**57**	**Total**	**0**	**Total**	**27**	**84**
	Bear	53			Wild cat	3	American mink[4]	23		Bear	51			Wild cat	3	
	Wolf	6			Badger	4	Hedgehog	8		Wolf	6			Badger	4	
					Fox	15	Tortoise	1						Fox	15	
					Marten	5	Bird	2						Marten	5	
							Goat	1								
							Dog	23								
							Cat	36								
							Unknown	5								
IT PNALM [2]	**Total**	**26**	**Total**	**114**	**Total**	**6**	**Total**	**0**	**146**	**Total**	**20**	**Total**	**105**	**Total**	**5**	**130**
	Bear	10	Red deer	58	Wild cat	6				Bear	4	Red deer	53	Wild cat	5	
	Wolf	16	Roe deer	31						Wolf	16	Roe deer	29			
			Wild boar	25								Wild boar	23			
IT PNM	**Total**	**28**	**Total**	**98**	**Total**	**42**	**Total**	**7**	**175**	**Total**	**25**	**Total**	**91**	**Total**	**38**	**154**
	Bear	3	Red deer	14	Wild cat	4	Hare	1		Bear	2	Red deer	13	Wild cat	4	
	Wolf	25	Roe deer	21	Badger	28	Hedgehog	2		Wolf	23	Roe deer	19	Badger	26	
			Wild boar	63	Fox	9	Squirrel	4				Wild boar	59	Fox	7	
					Marten	1								Marten	1	
RO Curbura Carpatilor	**Total**	**31**	**Total**	**0**	**Total**	**0**	**Total**	**0**	**31**	**Total**	**27**	**Total**	**0**	**Total**	**0**	**27**
	Bear	31								Bear	27					
ES Doñana - Sierra Morena [3]	**Total**	**185**	**Total**	**0**	**Total**	**0**	**Total**	**0**	**185**	**Total**	**120**	**Total**	**0**	**Total**	**0**	**120**
	Iberian lynx	185								Iberian lynx	120					
Total		**329**		**212**		**75**		**106**	**722**		**249**		**196**		**70**	**515**

[1]Originally 196 records, 1 cat, 5 cow, 2 dog, 1 goat, 2 marten deleted – no coordinates.

[2]Originally 149 records, 1 wild boar, 2 red deer deleted – wrong coordinates.

[3]Originally 189 records, 3 duplicities and 1 train collision deleted.

[4]American mink, an invasive species probably escaped from fur farms, was not included in the category wild carnivore.

Table 2. Number of target species individuals monitored by telemetry methods in each study area.

Study areas	Target Species	N individuals monitored	Mean interval between locations
GR Kastoria - Florina	Brown bear	**23**	Differences between bear individuals; 1 to 2 locations/hour
IT PNALM	Marsican Brown bear	**23**	Differences between bear individuals and months; in Summer season a mean of 1 location/hour
IT PNM	Marsican Brown bear	**1**	1 location/hour during 10 days/month
RO Curbura Carpatilor	Brown bear	**32**	Differences between bear individuals; 1 to 4 locations/2 hours
ES Doñana - Sierra Morena	Iberian lynx [(1)]	**-**	-
Total		**79**	

[1] Data not provided (see section 2.1).

c) Study areas and road network

For each country, two study areas were defined: the AVC study area and the Telemetry study area. Both areas were described as the area included in the polygon described by 1 km buffer around a Minimum Convex Polygon including 100% (MCP100) of the AVC and telemetry data respectively. In the AVC case only those points located not further than 50 m ('snapping' tolerance limit) from roads were included. In Spain, only AVC data were provided including two separate regions, Doñana and Sierra Morena, therefore AVC study area include two polygons.

The total length of road network included inside each study area is listed in Table 3, as well as the number of AVC and Brown Bear Crossings recorded in each category. The information was provided by partners from different sources and include different types of roads, mainly paved. Nevertheless, a small proportion of unpaved roads are also included in some countries where categories such as 'Unclassified' include both paved and unpaved, or by other reasons. In all countries (except Spain), unpaved was a small proportion of the total road length and just a few AVC (1 in GR, 3 in PNALM, 1 in PNM and 8 in ES) were recorded in this type of roads usually small and with low traffic intensity (see Table 3).

Table 3. Types of roads and total length of road network included in the AVC and Telemetry study areas in each project study areas.

Study area	Target species	Road network layer	Road classes included in the analysis	Pavement type	km AVC study area	km Telemetry study area	AVC	Crossings
GR Kastoria-Florina	Brown bear; Wolf	*roadnetwork* *OpenStreetMap*	Primary	Paved	83,2	137,1	8	137
			Secondary	Paved	618,0	896,0	18	952
			Tertiary	Paved	509,0	943,7	3	471
			Trunk	Paved	45,9	74,0	14	35
			Motorway	Paved	68,6	102,5	40	84
			Unclassified	Paved and Unpaved	297,9	493,1	1	407
			TOTAL		**1.622,5**	**2.646,4**	**84**	**2.086**

Table 3 (cont.). Types of roads and total length of road network included in the AVC and Telemetry study areas in each project study areas.

<table>
<tr><th>Study area</th><th>Target species</th><th>Road network layer</th><th>Road classes included in the analysis</th><th>Pavement type</th><th>km
AVC study area</th><th>km
Telemetry data</th><th>AVC</th><th>Crossings</th></tr>
<tr><td rowspan="6">IT PNALM</td><td rowspan="6">Marsican brown bear; wolf</td><td>pnalm_paved</td><td>CodDEA=10,18,20,21,22,30,40,50,
60,70,90,120,121,122,130,
140,150,160,170</td><td>Paved</td><td>186,5</td><td>221,1</td><td>119</td><td>1667</td></tr>
<tr><td>pnalm_unclassified_paved</td><td>CodDEA=70 AND CodFIS=10,20,30,40</td><td>Paved</td><td>115,5</td><td>198,5</td><td>9</td><td>1184</td></tr>
<tr><td>pnalm_unclassified</td><td>CodDEA=70 AND CodFIS=50,60,70,80,90,999</td><td>Paved and Unpaved</td><td>0,8</td><td>3,3</td><td>-</td><td>21</td></tr>
<tr><td>pnalm_unpaved</td><td>80,82,83,84</td><td>Unpaved</td><td>2,3</td><td>3,8</td><td>3</td><td>17</td></tr>
<tr><td rowspan="2">pnalm_unpaved</td><td>(CodDea = 0, CodFis = 0, 9)</td><td>Unclassified</td><td></td><td>95,1</td><td></td><td></td></tr>
<tr><td>TOTAL</td><td></td><td>305,1</td><td>521,8</td><td>131[1]</td><td>2889 (filtered 1 fix/hour)</td></tr>
</table>

[1] It includes a register of a Marsican brown bear collision that was also reported by IT PNM and that in further analyses are included in this area.

Table 3 (cont.). Types of roads and total length of road network included in the AVC and Telemetry study areas in each project study areas.

Study area	Target species	Road network layer	Road classes included in the analysis	Pavement type	km AVC study area	km Telemetry data	AVC	Crossings
IT PNM	Marsican brown bear; wolf	*pnm_paved*	CodDEA=10,18,20,21,22,30,40,50, 60,70,90,120,121,122,130, 140,150,160,170	Paved	196,6	141,6	148	168
		pnm_unclassified_paved	CodDEA=70 AND CodFIS=10,20,30,40	Paved	68,9	45,7	5	47
		pnm_unclassified	CodDEA=70 AND CodFIS=50,60,70,80,90,999	Paved and Unpaved	4,9	13,2	-	10
		pnm_unpaved	80,82,83,84	Unpaved	104,9	55,7	1	64
			TOTAL		**375,3**	**256,1**	**154**	**289** (filtered 1 fix/hour)

Table 3 (cont.). Types of roads and total length of road network included in the AVC and Telemetry study areas in each project study areas.

Study area	Target species	Road network layer	Road classes included in the analysis	Pavement type	km AVC study area	km Telemetry data	AVC	Crossings
RO Curbura Carpatilor	Brown bear	*drumuri_proiect*	**TOTAL**		**83,1**	**144,9**	**27**	**184**
ES Doñana – Sierra Morena	Iberian lynx	*vc01_1_carretera _arco*	CC	Paved	1897,2		68	-
			DC	Paved	300,0		29	
			Viario Urbano	Paved	155,4		0	
			Caminos	Paved and Unpaved	1051,4		8	
							15[1]	
			TOTAL		**3403,9**		**120**	

[1]AVC not located in roads that were not removed of the database but it has no effect on AVC cluster results because of snapping tolerance limit (50m); AVC located far from this distance were automatically excluded as a first step of KDE+ analysing process.

2.2 Data analysis

a) AVC clusters

For each region, the KDE+ method (Bíl et al., 2013) was applied to identify AVC clusters (including large carnivore, other carnivore and ungulate) and road crossing points clusters (telemetry data from monitored brown bear and Marsican brown bear individuals).

The KDE+ approach stems from the Kernel Density Estimation (KDE) method (e.g., Chung et al. 2011) which estimates the probability density function of the underlying data by the use of a kernel function (see Figure 4a). It is a nonparametric method which means that it does not make any assumption about the underlying distribution of AVC. Since there is no objectively determined threshold (see Figure 4b), KDE produces a range of local maxima (clusters). Therefore, the framework of the standard KDE method was extended by introducing repeated random simulations (Monte Carlo method) to objectively determine the level of significance (threshold), selecting only significant clusters and ranking them.

Risk locations are identified in places where the estimated probability density function exceeded the threshold. Remaining clusters are not statistically significant (see Figure 4c). Resulting significant clusters can be ranked according to cluster strength, which quantifies the degree of violation of the null hypothesis: 'AVC *are uniformly distributed along a road section'*. This process of statistical testing is, in contrast to other approaches, objective and allows the user to focus on important clusters. The ranking of the clusters makes it possible for the user to rank all the significant clusters from the most hazardous to the least.

The KDE method is usually implemented in GIS in a planar (2D) version. The outputs are raster images with a resolution defined by the user. However, a variant of the KDE method for one-dimensional data also exists. There are both 1D and 2D variants of this method. In our approach, a variant for one-dimensional data is better suited for our purposes because we work with data within a network, not within an area.

It is remarked that the KDE+ is applied to lines (transportation network), not to areas. It is not dependent on predefined section lengths. In addition, the KDE+ method typically returns more focused results than the KDE or other applied methods (Bíl et al., 2016).

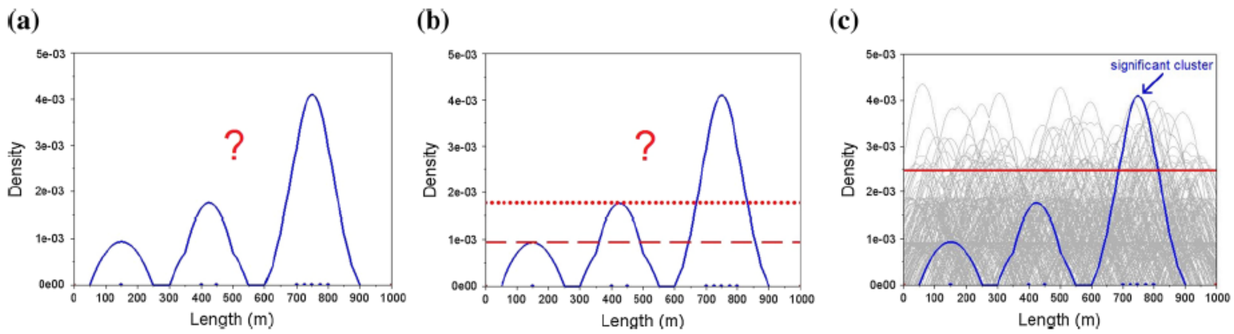

Figure 4. The KDE with an unknown threshold **(a)**, two subjectively chosen thresholds (*dashed and dotted lines*) **(b)** and the KDE+ method **(c)**. The *blue line* shows the estimated probability density function of AVC. The *grey lines*

represent KDEs of uniformly distributed data (Monte Carlo simulation). The horizontal red line is the 95th percentile level. (Figure extracted from Bíl, et al 2016).

The term 'significant cluster' can be explained as follows: roadkill data, when analysed using the KDE+ method, always form clusters. Some of them are spatially random and therefore not significant (i. e. not important for mitigation). On the other hand, some of them are spatially non-random = significant (also mentioned as 'hotspots').

There are two statistical tests which are applied in the KDE+ analysis, therefore, there are also two results with respect to the 'importance' for each cluster. The first test is applied to identify and localize significant clusters (the KDE+ method itself). The second test is applied to highlight the most important locations. Hence, three types of clusters are identified:

1. Non-significant cluster (not further processed).
2. **Significant cluster with 'low sureness'**, which could be false positives, due to the rather low cluster strength or low number of records in cluster.
3. **Significant clusters with 'high sureness'**, which only show 5 % or less probability of being false positive. Group 3 is subset of group 2.

To get the best benefit for cost of mitigation measures it is recommended to focus the application of mitigation measures on group 3 cluster, even though other clusters included in group 2 could also be considered (see Figure 5).

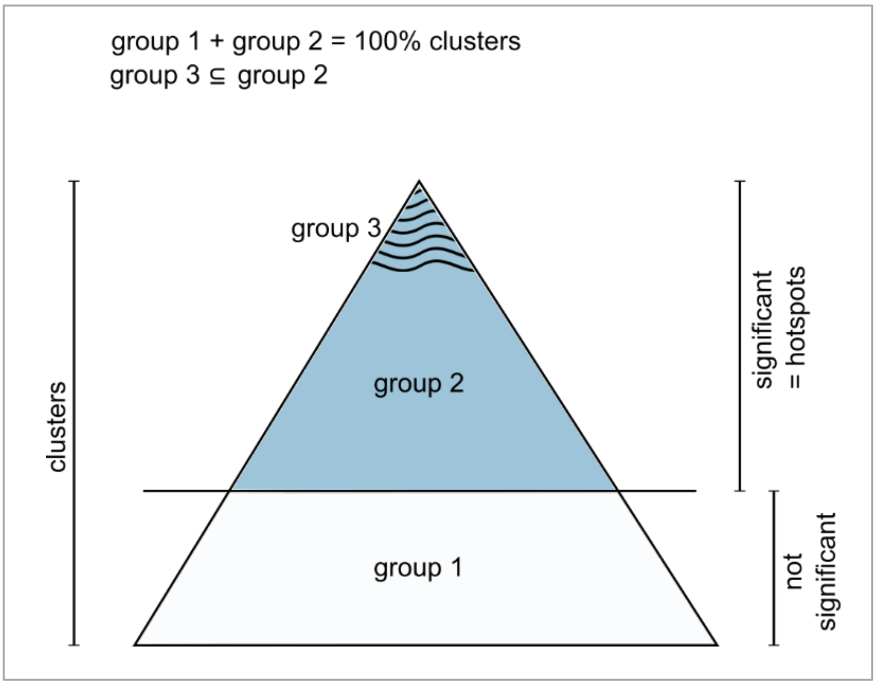

Figure 5. Types of clusters

b) Telemetry data

Crossing points

Lines (linear movement paths) were created from telemetry (GPS) points (according to animal/collar ID and time). Then intersections (crossing points) were determined between the lines and road segments. Afterwards, the KDE+ analyses were performed on these crossing points with the following filter: hour or less of time interval between start and end of telemetry linear move path (specifically 3.700 seconds and less) – 3.532 intersection points analysed (60% of total 8.939 points), no condition for time relevancy of telemetry used (whole time range since 2005).

Use of the areas beside roads

Two hexagonal grids (cells of 1 km and 400 m in diameter) were placed over the regions and time spent by monitored animals in each cell was estimated. Those cells more frequently used by animals, have associated a greater value of 'telemetry location time weight'.

First, the time weight of telemetry GPS points were calculated for each cell for every individual location and for every day of telemetry monitoring: *1 / [number of locations acquired in a particular day by concrete animal].* This procedure ensured not overrating the outcome weights of cell do to temporal/spatial correlation of location counts, since the more point density => the less weight of one point. For example, if for a radio tracked individual there was a time interval between positions of 1 hour, and 24 positions were recorded in a day => the weight of every single position became 1/24.

Finally, the resulting weight value was obtained by calculating the sum of point weights included in each hexagonal area performed with a filter to [number of telemetry point acquired in that day by that animal] equals 2 or more. This final values are the resulting parameter that indicates the amount of time spent (see Figure 6).

A distance of 100-400 m can be considered for bear's perception scale of the surroundings and/or response to 'roads risks' (Falcucci et al. 2009, Ditmer et al. 2018). The different grid sizes are provided to offer two different scales for evaluating the areas more frequently used by bear, for instance, the grid of 400 m could be interpreted as a scale of bear perception of the most immediate surrounding (e.g. for comparing the areas more used right next to a road), while 1 km draws the phenomenon in a greater scale, more related to land uses and habitat features of the areas nearby roads.

c) Cartography data elaboration

An online viewer was produced as a tool for exploring the different information layers of results. The access to the viewer (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php) is restricted by a password to ensure data confidentiality. Other files were also elaborated to help visualizing or evaluating the information (see Table 4).

Files of the main results were also sent to partners to allow further evaluation of them by using a Geographic Information System (GIS) software and/or other data manage software (see Table 4). GIS layers were all projected in the same Coordinate Representation System (ETRS89/EPSG:3035).

As mentioned before (see section a)), all clusters can be ranked according to their 'importance' (group 2 or 3 category). When working with **AVC cluster files** both cluster group types can be distinguished by the parameter 'upper interval of global strength' (GStr_Cl_1) value:

- Group 3: Clusters with values > 0 are considered as significant clusters with high sureness
- Group 2: Clusters with values < 0 as considered as significant clusters with low sureness).

To visualise files of the **area beside roads more insensibly used by brown bear**, user should represent parameter 'telemetry location time weight' (cnt_telem) included in shapefiles (see Table 4). This can be represented as a gradient quantity variable, where darker colour of a cell corresponds to an area more frequently used by target species (see Figure 6).

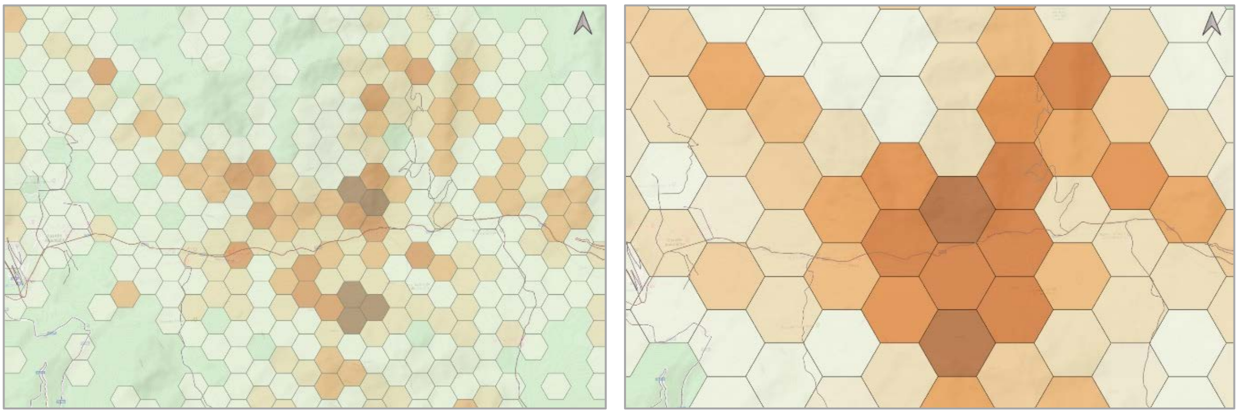

Figure 6. Use of the areas beside roads identified with hexagonal grid cells. Darker colour of a cell, area more frequently used by Brown bear and Marsican brown bear. Above, grid cell of 400 m diameter; below, grid cells of 1km diameter.

Table 4. Relation of data files elaborated to visualize and evaluate the analyses results. Files formats are indicated for each case as shapefile (shp.) or comma-separated values (csv.) files.

Data	**Layer's name on-line visor**	**File's name** (format)
AVC clusters	'AVC clusters'	'*region*_avc _clusters_etrs89' (shp.)
Crossing points clusters	'Telemetry clusters'	'*region*_telemetry_clusters_etrs89' (shp.)
Use of the areas beside roads		
400 m hexagonal grid	'weighted sum of telemetry points' (400 m diameter)'	'*region*_telemetry_hex400m' (shp.)
1000 m hexagonal grid	'weighted sum of telemetry points' (1 km diameter)'	'*region*_telemetry_hex1km' (shp.)
Estimated brown bear road crossing points	'Telemetry crossings'	-
AVC and Telemetry study areas	'Study area'	*'sc_studyareas_telemetryMPC_buff1km'* (shp.) *'study areas_snappedAVC_buff1km'* (shp.)
Road network	'Road segments'	-
AVC data used in the analysis	'AVC'	'*region*_avc' (csv.) '*region*_avc _etrs89' (shp.)
AVC data excluded from the analysis [1]	-	'*region*_avc _excluded (csv.)

[1] AVC registered before 2009 or involving species not included in the analysis (domestic animal, rodent, insectivore, reptile, bird and unknown species).

3. Results

3.1 Global results

A total of 46 AVC significant clusters (hotspots) were identified from data available in the overall of 13 study areas. From them 16 were 'high sureness clusters' (group 3 category, identified with highest probability to not be false positives) (see Table 5).

From the analysis of telemetry data, 141 significant road crossing points 'high sureness clusters' of target species were identified (all of them described as significant with high sureness, from group 3) (see Table 5).

In 6 cases, clusters identified by analysing AVC and telemetry data were found to be overlapped (4 cases in IT PNALM and 2 in GR Kastoria – Florina study areas, see Table 5).

The analysis of telemetry data in the hexagonal grid describes the areas where target species spent more time and should be also considered when identifying road sections to apply mitigation measures.

Since for some study areas AVC clusters have been identified by including also accidents involving other large mammals using similar habitats (e.g., ungulates), the total number of vehicle-collisions involving large carnivore inside the road sections identified as significant clusters should be considered too. Each partner should consider this information as it is important to be considered when choosing the best location where to implement mitigation measures.

Table 5. AVC and road crossing points clusters identified in each study area.

	AVC Data						Telemetry data	N overlaps AVC clusters/Road crossing point clusters
	N AVC used analysis			AVC density	N AVC clusters (hotspots)		N road crossing points clusters	
Study areas	**Target species [1]**	**Other wild species [2]**	**Total**	**AVC/ km**	**Significant with high sureness**	**Total**	**Total**	**Total**
GR Kastoria - Florina	57	27	84	0,05	1	6	43	2
IT PNALM	20	110	130	0,43	0	9	87	0
IT PNM	25	129	154	0,41	8	18	8	4
RO Curbura Carpatilor	27	0	27	0,32	3	5	3	0
ES Doñana - Sierra Morena [3]	120	0	120	0,04	4	8	-	-
Total	**249**	**266**	**515**	**-**	**16**	**46**	**141**	**6**

[1] Target species: Brown bear, Marsican brown bear, Iberian lynx and wolf.
[2] Other wild species: wild carnivores and ungulate.
[3] No telemetry movement registers of individuals collected for identification of areas most frequently used by Iberian lynx or crossing point clusters (see section 2.1)

3.2 Kastoria and Florina provinces (GR Kastoria-Florina)

a) Animal-vehicle collisions and brown bear monitored

In Kastoria and Florina study areas, from 2008 to 2018, a total of 59 AVC with large carnivore have been registered: 53 involving brown bear and 6 involving wolf. 57 of them took place from 2009 to 2018 and have been included in the AVC cluster analyses together with 27 other wild carnivore species (see Table 6., Figure 7 and section 2.1.).

Complementary, data of 23 brown bear movements were registered by telemetry methods in 2011-2018 and allowed to identify the areas more frequently used by brown bear and also the road crossing points clusters (see Table 6 and Figure 7.).

Table 6. Animal-Vehicle Collision (AVC) and telemetry gathered and included in the analyses.

GR Kastoria – Florina [1]			
AVC data		**Number**	**Included in the analysis**
Total AVC		185	84
Period		2008 - 2018	2009 - 2018
Species:	target (brown bear and wolf)	59 (31,89%)	57 (67,86%)
	ungulate	-	-
	wild carnivore	27 (14,59%)	27 (32,14%)
	other	99 (53,51%)	-
AVC density (AVC/km)		0,11	0,05
Road length (km)		1.622,53	
Telemetry data		**Collected and included in the analysis**	
N individuals monitored (brown bear)		23	
Period		07/04/2011 - 11/10/2018	
Telemetry GPS fixes		70.223	
Median of duration between fixes (s)		1.800	

[1] Research permit numbers: 7ΑΓΘ4653Π8-Φ50 and 4ΑΘ60-Η, both issued by the Hellenic Ministry of Environment and Energy.

b) Results of AVC and road crossing points clusters

In overall:

- 6 AVC clusters were identified: 4 clusters located in Kastoria region, and 2 in Florina. From the latest region, 1 AVC cluster was described as significant cluster with high sureness (see Table 7 and Figure 7).
- 43 significant road crossing points clusters were identified: 36 clusters located in the region of Kastoria, 7 in Florina province. In 2 cases, one for each study region, AVC clusters were found to overlap with 2 road crossing points clusters (see Table 7 and Figure 7).

In Kastoria and Florina study areas, the following roads were identified as conflictive road stretches were mitigation measures could be required (Actions A4 and A5):

- A-29 (Actions A4)
- E-86/ E-65 (Actions A5)

Most of the AVC clusters identified by the analyses are included in these roads: 4 AVC clusters on A-29 Egnatia's Highway, 1 on E-65 road and 1 along another road in Florina study area (described as significant with high sureness). The lack of identified AVC clusters on E-86, might be probably due to low number of AVC data and a disperse distribution of the accidents on this road (see Table 7 and Figure 7).

In relation to road crossing points analysis, 43 clusters have been identified: 2 located on A-29 and 1 on E-65, while the rest of 40 road crossing points clusters were distributed along other roads in both, Kastoria and Florina study areas (see Table 7 and Figure 7). 2 AVC clusters were found to overlap with 2 road crossing points clusters (one on A-29 road and one E-65 road).

Table 7. Animal-Vehicle Collisions (AVC) and crossing points clusters identified in the study area and roads where they are located.

GR Kastoria - Florina			
Clustering results	**Number**	**Roads (total AVC clusters)**	**N AVC clusters significant with high sureness**
AVC clusters (hotspots)	6	**A-29** (4) **E-65** (1) Other roads (1)	0 0 1
AVC inside AVC clusters	14 (16,67%)	-	-
Road crossing points clusters	43	**A-29** (2) **E-65** (1) Other roads (40)	2 1 40
N overlaps AVC clusters/Road crossing point clusters	2	**A-29** (1) **E-65** (1)	- -

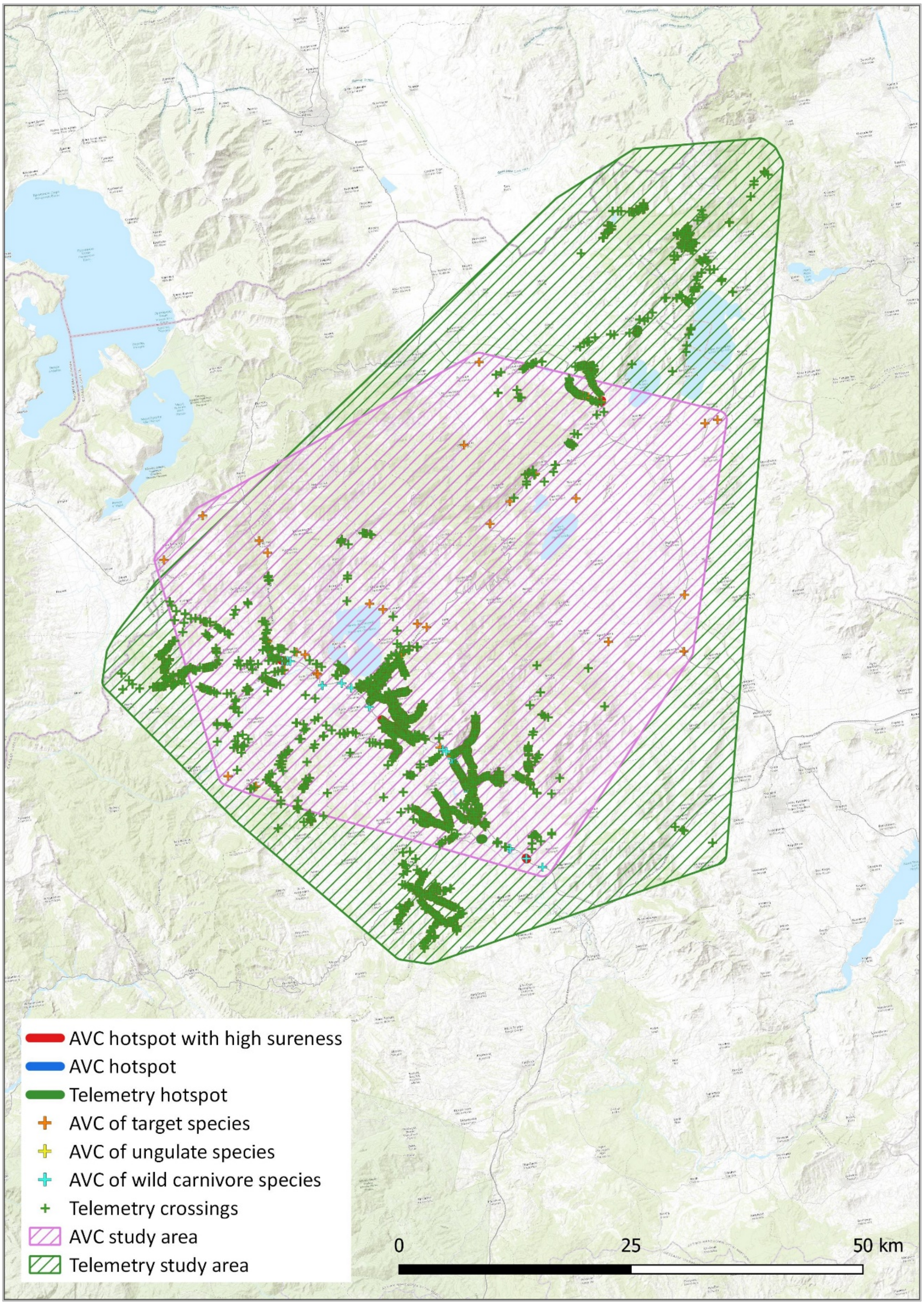

Figure 7. Image of the study area GR Kastoria - Florina from the website created for allowing the visualisation of data analysis results (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php). Detailed information has been provided to each partner in layer files that could be displayed and analysed with a GIS software.

3.3 Abruzzo, Lazio and Molise National Park (IT PNALM)

a) Animal-vehicle collisions and Brown bear monitored

In PNALM area, from 1972 to 2018, a total of 26 AVC with large carnivore have been registered: 10 involving Marsican brown bear and 16 involving wolf. 20 of them took place from 2009 to 2018 and were included in the AVC cluster analyses together with 105 AVC caused by ungulates and 5 by other wild carnivore species (see Table 8, Figure 8 and section 2.1.).

Complementary, data of 23 Marsican brown bear movements were registered by telemetry methods in 2005-2018 and allowed to identify the areas more frequently used by brown bear and also the road crossing points clusters (see Table 8 and Figure 8).

Table 8. Animal-Vehicle Collision (AVC) and telemetry gathered and included in the analyses.

IT PNALM			
AVC data		**Number**	**Included in the analysis**
Total AVC		146	130
Period		1972 - 2018	2009 - 2018
Species:	target (brown bear and wolf)	26 (17,81%)	20 (15,38%)
	ungulate	114 (78,08%)	105 (80,77%)
	wild carnivore	6 (4,11%)	5 (3,85%)
	other	-	-
AVC density (AVC/km)		0,48	0,43
Road length (km)		305,10	
Telemetry data		**Collected and included in the analysis**	
N individuals monitored (brown bear)		23	
Period		07/07/2005 - 09/12/2018	
Telemetry GPS fixes		62.736	
Median of duration between fixes (s)		3.600	

b) Results of AVC and road crossing points clusters

In overall:

- 9 AVC clusters were identified, none of them described as a significant cluster with high sureness (see Table 9 and Figure 8).
- 87 significant Marsican brown bear road crossing points clusters were identified, none of them overlapped with any AVC cluster (see Table 9 and Figure 8).

In the study area the following roads were identified as conflictive road stretches were mitigation measures could be required (Actions A4 and A5):

- SS-83 (Actions A4 and A5)
- SR-509 (Action A5)
- SP-174 (Action A5)

All AVC clusters identified by the analyses are included in these roads. All 9 AVC clusters identified are located on road SS-83. The lack of identified AVC clusters on SR-509 and SP-174 could be due to low number of AVC data and a disperse distribution of the accidents (see Table 9 and Figure 8).

In relation to road crossing points analysis, 87 clusters have been identified: 29 located on SS-83 road and 25 on SP-509 road, while the rest of 33 road crossing points clusters were distributed along other roads in the study area (see Table 9 and Figure 8).

Table 9. Animal-Vehicle Collisions (AVC) and crossing points clusters identified in the study area and roads where they are located.

IT PNALM			
Clustering results	**Number**	**Roads (total AVC clusters)**	**N AVC clusters significant with high sureness**
AVC clusters (hotspots)	9	**SS-83** (9)	0
AVC inside AVC clusters	23 (17,69%)	-	-
Road crossing points clusters	87	**SS-83** (29) **SR-509** (25) Other roads (33)	29 25 33
N overlaps AVC clusters/Road crossing point clusters	0	-	-

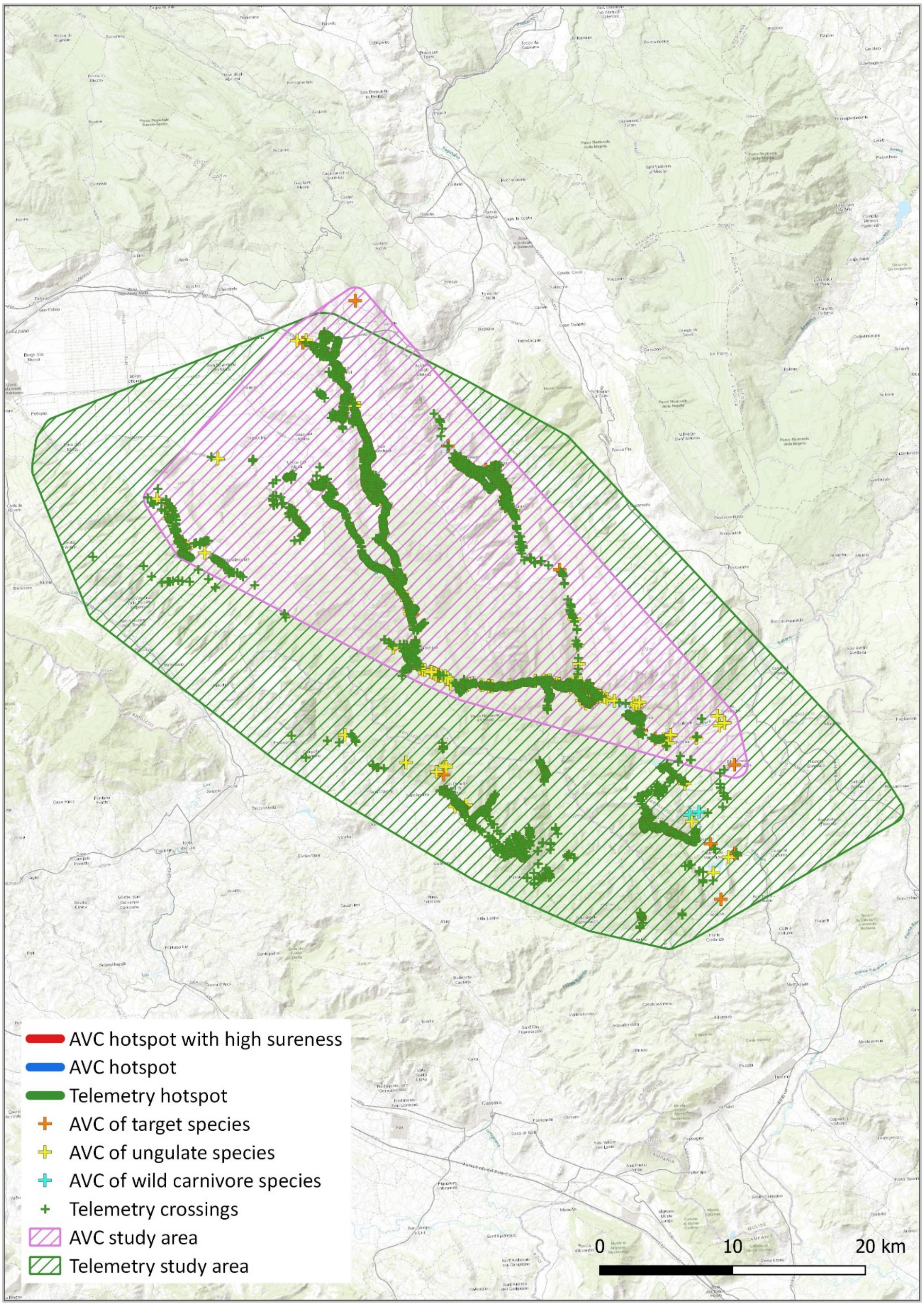

Figure 8. Image of the study area IT PNALM: Abruzzo, Lazio and Molise National Park from the website created for allowing the visualisation of data analysis results (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php). Detailed information has been provided to each partner in layer files that could be displayed and analysed with a GIS software.

3.4 Majella National Park (IT PNM)

a) Animal-vehicle collisions and Brown bear monitored

In PNM area, from 1991 to 2018, a total of 28 AVC with large carnivore have been registered: 3 involving Marsican brown bear and 25 involving wolf. 25 of them took place from 2009 to 2018 and have been included in the AVC cluster analyses together with 91 AVC caused by ungulates and 38 by other wild carnivore species (see Table 10, Figure 9 and section 2.1.).

Complementary, data of 1 Marsican brown bear movements were registered by telemetry methods in 2015-2017 and allowed to identify the areas more frequently used by brown bear and also the road crossing points clusters (see Table 10 and Figure 9).

Table 10. Animal-Vehicle Collision (AVC) and telemetry gathered and included in the analyses.

IT PNM			
AVC data		**Number**	**Included in the analysis**
Total AVC		175	154
Period		1991 - 2018	2009 - 2018
Species:	target (brown bear and wolf)	28 (16,00%)	25 (16,23%)
	ungulate	98 (56,00%)	91 (59,09%)
	wild carnivore	42 (24,00%)	38 (24,68%)
	other	7 (4,00%)	-
AVC density (AVC/km)		0,47	0,41
Road length (km)		375,30	
Telemetry data		**Collected and included in the analysis**	
N individuals monitored (brown bear)		1	
Period		03/03/2015 - 04/03/2017	
Telemetry GPS fixes		6.390	
Median of duration between fixes (s)		1.800	

b) Results of AVC and road crossing points clusters

In overall:

- 18 AVC clusters were identified, from which 8 AVC clusters were described as significant clusters with high sureness (see Table 11 and Figure 9).
- 8 significant road crossing points clusters were identified. In 4 cases, AVC clusters were found to overlap with 2 road crossing points clusters (see Table 11 and Figure 9).

In the study area, the following roads were identified as conflictive road stretches were mitigation measures could be required (Actions A4 and A5):

- SP-487 (Actions A4 and A5)
- SS-5 (Actions A4 and A5)
- SS-17 (Actions A4 and A5)
- SP-84 (Action A5)

All AVC clusters identified by the analyses are included in these roads: 4 AVC clusters on SP-487 road (2 of them described as high sureness significance clusters), 12 on SS-17 (5 described as high sureness significance clusters) and 2 on SS-5 (1 described as high sureness significant cluster) (see Table 11 and Figure 9).

In relation to road crossing points analysis, 8 clusters have been identified: 2 located on SP-487, 2 located on SS-17 and the other 4 cases, along other roads of the study area (see Table 11and Figure 9). On SS-17 road, 4 AVC clusters were found to overlap with 2 road crossing points clusters.

Table 11. Animal-Vehicle Collisions (AVC) and crossing points clusters identified in the study area and roads where they are located.

IT PNM			
Clustering results	**Number**	**Roads (total AVC clusters)**	**N AVC clusters significant with high sureness**
AVC clusters (hotspots)	18	**SP-487** (4) **SS-17** (12) **SS-5** (2)	2 5 1
AVC inside AVC clusters	55 (35,71%)	-	-
Road crossing points clusters	8	**SP-487** (2) **SS-17** (2) Other roads (4)	2 2 6
N overlaps AVC clusters/Road crossing point clusters	4	**SS-17** (4)	2

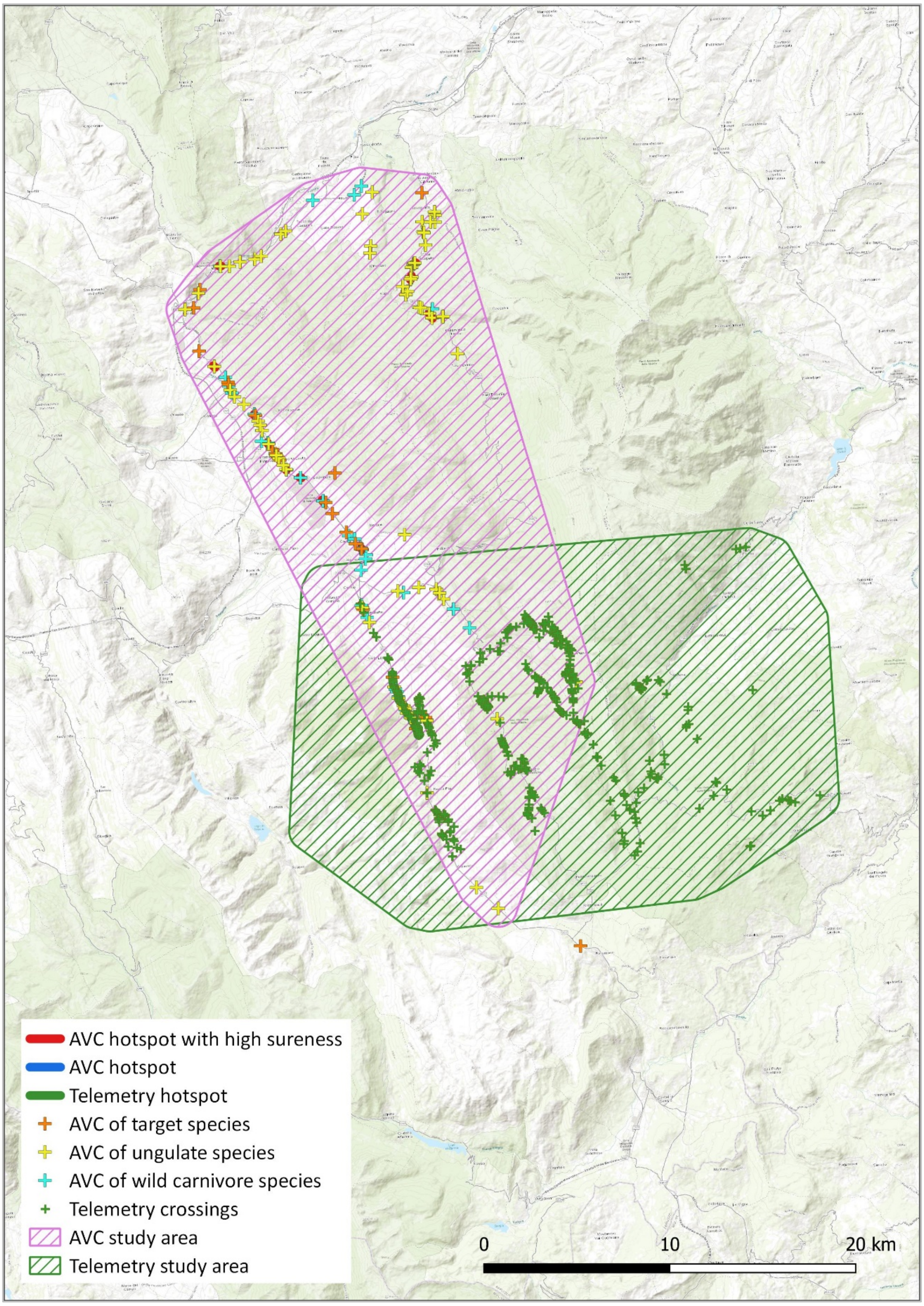

Figure 9. Image of the study area IT PNM: Majella National Park from the website created for allowing the visualisation of data analysis results (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php). Detailed information has been provided to each partner in layer files that could be displayed and analysed with a GIS software.

3.5 South-Eastern Carpathians (RO Curbura Carpatilor).

a) Animal-vehicle collisions and Brown bear monitored

In South-Eastern Carpathians study area, from 2007 to 2018, a total of 31 AVC with large carnivore have been registered, all of them involving brown bears. 27 of them took place from 2009 to 2018 and have been included in the analyses of AVC clusters (see Table 12, Figure 10 and section 2.1.). In this study area, there were no collection of other AVC registers involving other mammal species.

Complementary, data of 32 brown bear movements were registered by telemetry methods in 2006-2019 and allowed to identify to identify the areas more frequently used by brown bear and also the road crossing points clusters (see Table 12 and Figure 10).

Table 12. Animal-Vehicle Collision (AVC) and telemetry gathered and included in the analyses.

RO Curbura Carpatilor			
AVC data		**Number**	**Included in the analysis**
Total AVC		31	27
Period		2007 - 2018	2009 - 2018
Species:	target (brown bear)	31 (100,00%)	27 (100,00%)
	ungulate	-	-
	wild carnivore	-	-
	other	-	-
AVC density (AVC/km)		0,37	0,32
Road length (km)		83,10	
Telemetry data		**Collected and included in the analysis**	
N individuals monitored (brown bear)		32	
Period		20/07/2006 - 28/02/2019	
Telemetry GPS fixes		70.954	
Median of duration between fixes (s)		3.614	

b) Results of AVC and road crossing points clusters

In overall:

- 5 AVC clusters were identified, from which 3 AVC clusters were described as significant clusters with high sureness (see Table 13).
- 3 significant road crossing points clusters were identified, none of them overlapped with AVC clusters (see Table 13 and Figure 10).

In the study area, the following roads were identified as conflictive road stretches were mitigation measures could be required (Actions A4 and A5):

- DN13/E60 (Actions A4 and A5)
- DN1A (Actions A4 and A5)
- DN1/E68 (Actions A4 and A5)

All AVC clusters identified by the analyses are included in these roads: 4 clusters on DN13/E60 road (2 of them described as high sureness significance clusters) and 1 cluster significant cluster with high sureness on DN1A. The lack of identified AVC clusters on DN1/E68, could be due to low number of AVC data and a disperse distribution of the accidents on this road (see Table 13 and Figure 10).
In relation to road crossing points analysis, 3 clusters have been identified: 1 cluster located on DN13/60, 1 on DN1A and the other one along another road in the study area (see Table 13 and Figure 10).

Table 13. Animal-Vehicle Collisions (AVC) and crossing points clusters identified in the study area and roads where they are located.

RO Curbura Carpatilor			
Clustering results	**Number**	**Roads (total AVC clusters)**	**N AVC clusters significant with high sureness**
AVC clusters (hotspots)	5	**DN13/E60** (4) **DN1A** (1)	2 1
AVC inside AVC clusters	11 (40,74%)	-	-
Road crossing points clusters	3	**DN13/E60** (1) **DN1A** (1) Other roads (1)	1 1 1
N overlaps AVC clusters/Road crossing point clusters	0	-	-

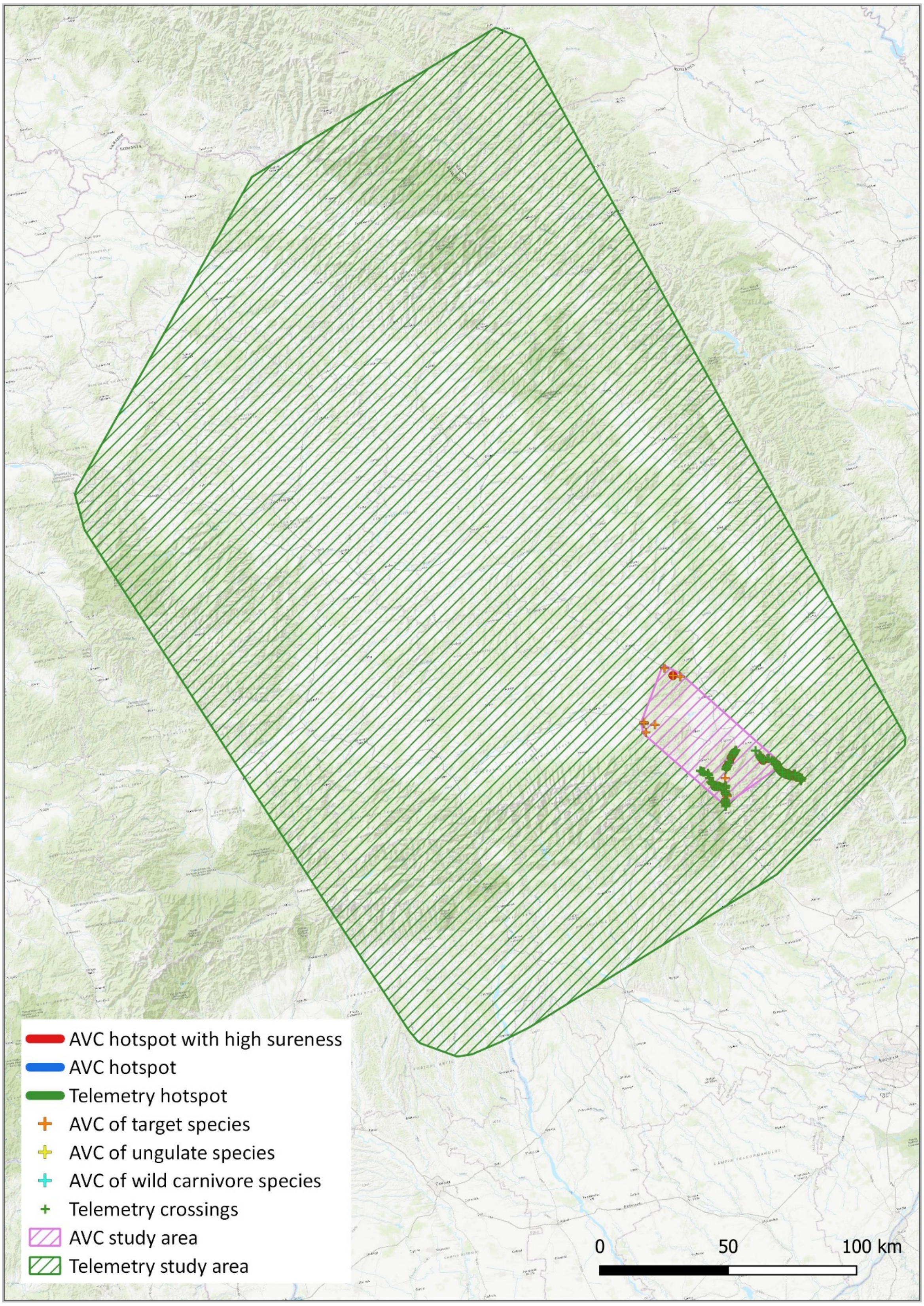

Figure 10. Image of the study area RO Curbura Carpatilor from the website created for allowing the visualisation of data analysis results (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php). Detailed information has been provided to each partner in layer files that could be displayed and analysed with a GIS software.

3.6 Doñana National Park and Sierra Morena (ES Doñana - Sierra Morena)

a) Animal-vehicle collisions

In National Park of Doñana and Sierra Morena study areas, from 1979 to 2019, a total of 185 AVC with large carnivore have been registered, all of them involving Iberian lynxes. 120 of them took place from 2009 to 2018 and have been included in the analyses of AVC clusters (see Table 14, Figure 11 and section 2.1.). In this study area, there were no collection of other AVC registers involving other mammal species, neither telemetry movement of individuals for identifying areas most frequently used by Iberian lynx or crossing point clusters (see section 2.1.).

Table 14. Animal-Vehicle Collision (AVC) gathered and included in the analysis.

ES Doñana - Sierra Morena			
AVC data		**Number**	**Included in the analysis**
Total AVC		185	120
Period		1979 - 2019	2009 - 2018
Species:	target (Iberian lynx)	185 (100,00%)	120 (100,00%)
	ungulate	-	-
	wild carnivore	-	-
	other	-	-
AVC density (AVC/km)		0,05	0,04
Road length (km)		3.403,90	

b) Results of AVC clusters

In overall, 8 AVC clusters were identified, from which, 4 AVC clusters were described as significant clusters with high sureness (see Table 15 and Figure 11).

In the study area, the following roads were identified as conflictive road stretches were mitigation measures could be required (Actions A4 and A5):

- A-481 (Actions A4 and A5)
- A-3001 (Actions A4 and A5)
- A-421 (Actions A4 and A5)

Some AVC clusters identified by the analyses are included in these roads: 2 clusters on A-481 road (1 of them described as high sureness significance clusters) and 1 significant cluster with high sureness on A-421. The rest of the 5 AVC clusters identified are located on other roads included in the study areas: 1 cluster in National Park of Doñana and 4 on Sierra Morena region. The lack of identified AVC clusters on A-3001, might be probably due to low number of AVC data and a disperse distribution of the accidents on this road (see Table 15 and Figure 11).

Table 15. Animal-Vehicle Collisions (AVC) clusters identified in the study area and roads where they are located.

ES Doñana - Sierra Morena			
Clustering results	**Number**	**Roads (total AVC clusters)**	**N AVC clusters significant with high sureness**
AVC clusters (hotspots)	8	**A-481** (2) **A-421** (1) Other roads (5)	1 1 2
AVC inside AVC clusters	19 (15,70%)	-	-

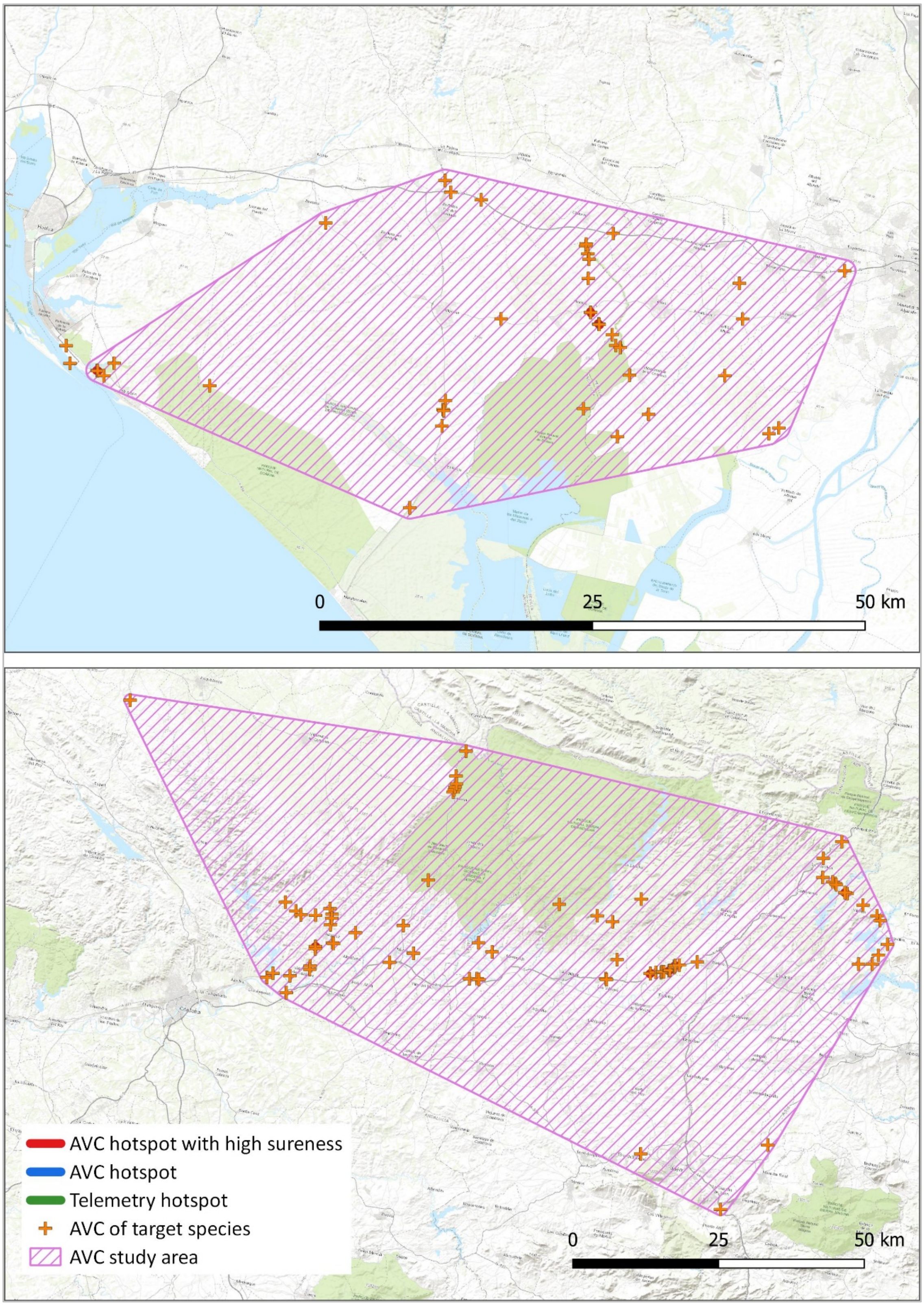

Figure 11. Image of the study areas ES Doñana – Sierra Morena from the website created for allowing the visualisation of data analysis results (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php). Detailed information has been provided to each partner in layer files that could be displayed and analysed with a GIS software.

4. Conclusions

Action A3 has **allowed to compile information and apply a standard method to analyse data regarding AVC involving large carnivore, and also data on Brown bear movements close to roads obtained by telemetry.** The free software KDE+ has been applied to identify road sections with significant higher risks of AVC occurrence (AVC hotspots). It has also enabled to identify road sections where a high number of crossings is estimated (crossing hotspots) based on the presence of areas intensively used by some individuals in both sides of the roads. Road sections where frequent Brown bear crossing is estimated often do not correspond with AVC hotspots. This fact can be due to a variety of factors regarding landscape, road and traffic features or to the existence of viaducts, tunnels or other over or underpasses allowing a safe crossing of the transport infrastructure by wildlife.

Data analyses approach applied is innovative because provide not only **AVC location and hotspots** (traditionally used to identify road sections where mitigation measures to reduce road mortality should be applied), but also **information about areas most intensively used by large carnivores close to roads**. Compared to usual methods, exclusively focused on identifying the road/railway sections with the highest risk of AVC, the approach applied in this Action provides complementary information on the ecology of wildlife species in relation to the infrastructure that are not directly related to mortality events. This information could be used to discern areas were to undertake field inspections for identifying transversal structures used as wildlife crossings, or other possible reasons related to the land use or surrounding environment that provide safe crossing corridors.

The results of the analyses undertaken has been delivered to each partner in two complementary ways. A **website-based viewer** allows a fast and comfortable view of the areas where each AVC has been registered, overlapped to AVC hotspots, crossing hotspots and identification of areas more frequently used by animals. The **GIS layers** produced will allow further detailed analyses.

Results provided for each study area are **valuable information to assess decision making in order to determine road sections where the application of mitigation measures will result on highest benefits** in terms of mortality reduction. Nevertheless, the analyses show limitations due to the lack of systematic registration of all collisions involving large carnivores that results in a relatively low number of AVC that obligated to include also accidents involving other wildlife species (such as ungulates) that may also share similar space usage patterns. Due to this constraints, **expert and local knowledge on target species pattern movements and particularities of each study area is extremely valuable**.

The data analyses approach applied has a **potential to be used in future project and study areas**. Nevertheless, in many countries data from AVC accidents are not systematically recorded. So, the implementation of standardized gathering of data about all AVC involving large carnivore, including accurate location of the event, is an essential first step to apply a scientific based approach when selecting the priority areas where mitigation measures should be applied.

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