ACTION A5. DESCRIPTION OF TARGET ROAD SEGMENTS, IDENTIFICATION OF CROSSING POINTS USED BY ANIMALS AND ANALYSIS OF TRAFFIC VOLUME AND SPEED

ACTION REPORT/2020 – Greece

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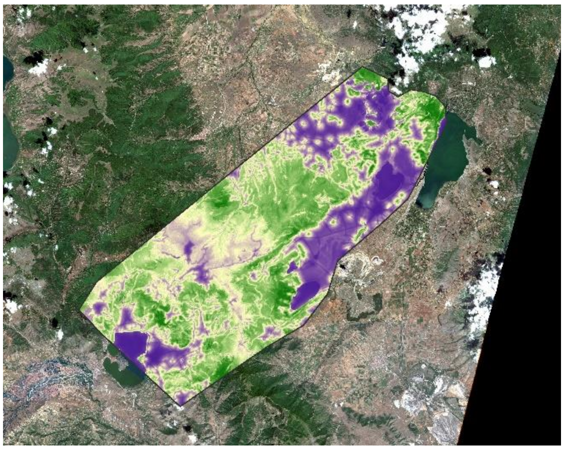

LIFE SAFE CROSSING
PREVENTING ANIMAL-VEHICLE COLLISIONS

EGNATIA ODOS S.A.

Callisto
Wildlife and Nature Conservation Society

NATURA 2000

COSMOTE

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1. Executive summary

This report presents the results of the preparatory action A5 which is part of the implementation of the LFE SAFE CROSSING program. The aim of this action is the description of target road segments, the identification of crossing points used by animals and the analysis of traffic volume and speed of the vehicles with emphasis on the targeted species in Greece: the brown bear (Ursus arctos).This action is needed as a preparatory action for Action C1 implementation, in order to allow the precise identification of the six (6) sites/locations (foreseen in Greece) where the Anti-Vehicle-Collision devices will be installed in order to minimize the probabilities of bear traffic collisions and thus the repercussions of road mortality of bear population status in GR. Action C1 illustrates at the same time the replicability of the same action developed in the frame of the previously implemented project in Italy, "LIFE STRADE". The investigated four (4) road segments are included in both project sub-areas in Greece (Prefectural Unit of Florina and Prefectural Unit of Kastoria). Their locations and length are identified as follows:

a) Road segment 1 (New National Road Amyndaio-Vevi – R.U. Florina) E86-E65- (length 11km)
b) Road segment 2 (Old National Road Amyndaio-Kleidi – R.U. Florina) E86: (length 11km)
c) Road segment 3 (sub-segment (1)): Pedino -Aetos- Agrapidies- Sklithro-Asprogeia – R.U. Florina): (length 11km)
d) Road segment 4 : Fotini - Metamorfosi -subsitute to Neapoli - Kastoria old national road- R.U Kastoria) (length 4km)

The implementation of this action included the combination of (3) methodological protocols as follows:

(a) in situ field investigations at different seasons for each road segment in order to record with GPS the different key variables such as: wildlife crossings (through biosigns detection), lands use. Micro-landscape characteristics etc.

b) Traffic volume and speed measuremrnts: For each selected road segment regular measurements of traffic volume and vehicles speed were performed using a specialized traffic and speed counter device with a rotation system in order to cover all road segments.

c) Camera traps: In each road segment camera traps were installed to monitor wildlife at the selected crossing points at different seasons of the total monitoring period.

After completion of the above protocols, data entry and compilation of the gathered information combined to digitized information layers regarding key environmental parameters (i.e. landuse, road network, bear presence and activity, micro-landscape characteristics etc), a multivariate statistical analysis was performed in order to identify with the highest precision possible the (6) locations for the installation of the AVC's devices that will be realized under action C1.

2. Preface

The current intensive land exploitation along with urban development causes degradation and irreversible changes in landscape structure as well as in its ecological functions (Vitousek et al. 1997; Primack 2012). The massive increase of anthropogenic barriers in the form of infrastructure severely disrupts natural biological processes due to habitat loss and fragmentation (EEA 2011) and thus negatively influences wildlife populations (Forman and Alexander 1998; Iuell et al. 2003). Distribution of suitable habitats and various resources in highly fragmented landscapes is often nonrandomly scattered, and animals have to overcome a large amount of anthropogenic barriers that are mainly represented by road networks (Andrén 1994; Iuell et al. 2003; Vaiškūnaitė et al. 2012). As a consequence, the frequency of wildlife vehicle collisions has increased significantly during the last decades, and expanding traffic represents a major threat to several wildlife species in human-dominated landscapes (Forman and Alexander 1998; Underhill and Angold 2000; Fahrig and Rytwinski 2009; Riley et al. 2006; Benítez-López et al. 2010; Carvalho and Mira 2011).

Carnivores (Mammalia: Carnivora) are the most sensitive and vulnerable group to the rapid development of road infrastructure due to their specific life-history characteristics such as low population densities and large home ranges (Clarke et al. 1998; Forman and Alexander 1998; Forman 2003; Fahrig and Rytwinski 2009; Grilo et al. 2009; Basille et al. 2013). Many studies have demonstrated that road mortality can reduce survival and population densities and that collisions with vehicles are one of the main sources of mortality of many carnivore species (Paquet 1993; Waser 1996; Taylor et al. 2002). For example, traffic caused almost 20% of total brown bear (Ursus arctos) mortality in Croatia (Kusak et al. 2000), more than 40 % of adult Eurasian badger Meles meles mortality and 60 % of Eurasian otter (Lutra lutra) mortality in Great Britain (Woodroffe 1994; Clarke et al. 1998). For endangered carnivore species with small geographic range, road mortality can significantly contribute to their quick decline or population extinctions (e.g. Iberian lynx Lynx pardinus; Ferreras et al. 1992).

Moreover, road infrastructure influences carnivore behavioural responses (e.g. shifts in activity patterns, Baker et al. 2007) and road avoidance due to traffic intensity associated with noise and light pollution (Forman and Alexander 1998; Underhill and Angold 2000; Sherwood et al. 2003). Reduced landscape permeability (barrier effect) and road avoidance may subsequently result in limited gene flow among individual subpopulations (Riley et al. 2006; Frantz et al. 2010; Huck et al. 2010; Jackson and Fahrig 2011) which could cause a loss of genetic diversity and ultimately local population extinctions. Hence, an understanding of the spatiotemporal pattern of carnivore road mortality is an essential tool for their effective conservation, especially in human-dominated landscapes with the highest proportion of traffic infrastructure (Iuell et al. 2003).

Despite the considerable research interest in wildlife vehicle collisions during the past decades, influence of different factors at various spatial scales associated with the carnivore road mortality risk is still poorly understood. In particular, the influence of composition and configuration of surrounding landscape, road-related characteristics or traffic intensity have varying effects on carnivore road mortality patterns (Grilo et al. 2009; Gunson et al. 2011; Basille et al. 2013).

At the larger spatial scale, distribution of road mortality may be connected with representation of preferable species-specific habitats that are important predictors of carnivore distribution, large-scale population density and diversity (Virgós et al. 2002; Gehring and Swihart 2003). Furthermore, the highest collision risk may be related to the presence of specific habitat structures at the local spatial scale (Clevenger et al. 2003; Grilo et al. 2009; Basille et al. 2013; Barthelmess 2014). For example, the presence of linear habitats such as corridors or forest edges, which have been demonstrated to be viable elements for movements for several carnivore species, may increase road mortality risk (Clevenger et al. 2003; Hilty et al. 2006; Barthelmess 2014).

Finally, another set of characteristics which may markedly affect road mortality risk is represented by the road topography (Hlaváč and Anděl 2001; Grilo et al. 2009). For example, roads that are parallel to roadside vegetation were significantly associated with higher carnivore road mortality in contrast to raised or buried roads (Grilo et al. 2008, 2009; Glista et al. 2009). The understanding of carnivore-vehicle patterns thus needs a comprehensive approach encompassing analysis of several different factors on various spatial scales.

3. Introduction.

3.1 The LIFE SAFE CROSSING project

The LIFE SAFE CROSSING Project with the full title: "Preventing Animal-Vehicle Collisions – Demonstration of Best Practices targeting priority species in SE Europe" aims at implementing actions to reduce the impact of roads on some priority species in four European countries:

- Marsican brown bear and wolf in Italy,
- Iberian lynx in Spain,
- Brown Bear in Greece and Romania.

The target species are severely threatened by road infrastructures, both by direct mortality as well as by the barrier effect.

The LIFE SAFE CROSSING is based on the experience of LIFE STRADE project (LIFE11BIO/IT/072, www.lifestrade.it) which has developed an innovative tool for the prevention of road kills, and the results of the experimentation in 17 sites have been very promising and wildlife mortality on roads was reduced up to 100% in the intervention areas. It was also seen that one of the main causes of the road kills is the low level of awareness and attention of drivers regarding the risk of collisions with wildlife.

The project therefore aims at the following objectives:

- Demonstration of the use of the innovative Animal-Vehicle Collision (AVC) Prevention tools in new project areas.
- Reduction of the risk of traffic collisions with the target species.
- Improve connectivity and favor movements for the target populations.
- Increase the attention of drivers in the project areas about the risk of collisions with the target species.

The core of the project will be the demonstration of an innovative tool for roadkill prevention to new areas. This will be accompanied by best practices to restore wildlife passages in order to favor the movements of animals across roads. These actions will be prepared by an evaluation of the impact and distribution of traffic infrastructures on the target species.

The implementation of communication activities for drivers also strongly contribute to reduce the danger of road kills. Finally, in the scope of a demonstration project, activities are planned to further replicate the implemented activities, mainly the innovative ones.

The duration of the project is 5 years (September 2018 – October 2023) and its implementation is coordinated by the Italian organization AGRISTUDIO in cooperation within total 13 partners from Italy, Spain, Romania and Greece. Greek partners of the project are:

- EGNATIA ODOS S.A.
- Region of Western Macedonia
- COSMOTE
- NGO Callisto

The project will disseminate an innovative tool for the prevention on road kills, which has been developed in the LIFE STRADE project, to new areas, thus providing a new important management tool. This, together with best practices creation of wildlife passages, will greatly reduce the number of animals killed on roads and enhance connectivity. The concrete conservation actions and the information campaigns for drivers will represent a significant impact not only for the target species but for the overall biodiversity of the project areas. More Specifically, the following results are expected:

- Installation of at least 27 AVC Prevention Systems as demonstration to new areas (6 systems will be installed in Greece: 3 in the Regional Unit of Florina and 3 in the Regional Unit of Kastoria).
- Readaptation of at least 80 wildlife crossing structures (50 in A29 highway in Greece).
- Interventions for roadkill prevention on at least 400 km (in all 4 project partner countries), of which 37 km in Greece on national and county road network.
- Decrease of mortality of target species due to road fatalities with vehicles of at least 50% in the areas of intervention.
- Reduction of speed of at least 30% of vehicles as a reaction to the prevention activities.
- Knowledge of the AVC prevention System to at least 100 decision makers.

As far as Greece is concerned, six (6) "Anti-Vehicle-Collision-Systems" (AVC's) (see fig. 1) are planned to be installed at (6) different locations along four (4) different road segments of the national and county road network as follows: (a) Road segment 1 (New National Road Amyndaio-Vevi – R.U. Florina) E86-E65 (11km), (b) Road segment 2 (Old National Road Amyndaio-Kleidi – R.U. Florina) E86 (11km), (c) Road segment 3 (sub-segment (1)): Pedino-Aetos- Agrapidies- Sklithro-Asprogeia – R.U. Florina)(11km) and

(d) Road segment 4 : Fotini - Metamorfosi -subsitute to Neapoli - Kastoria old national road-R.U Kastoria) (4km).

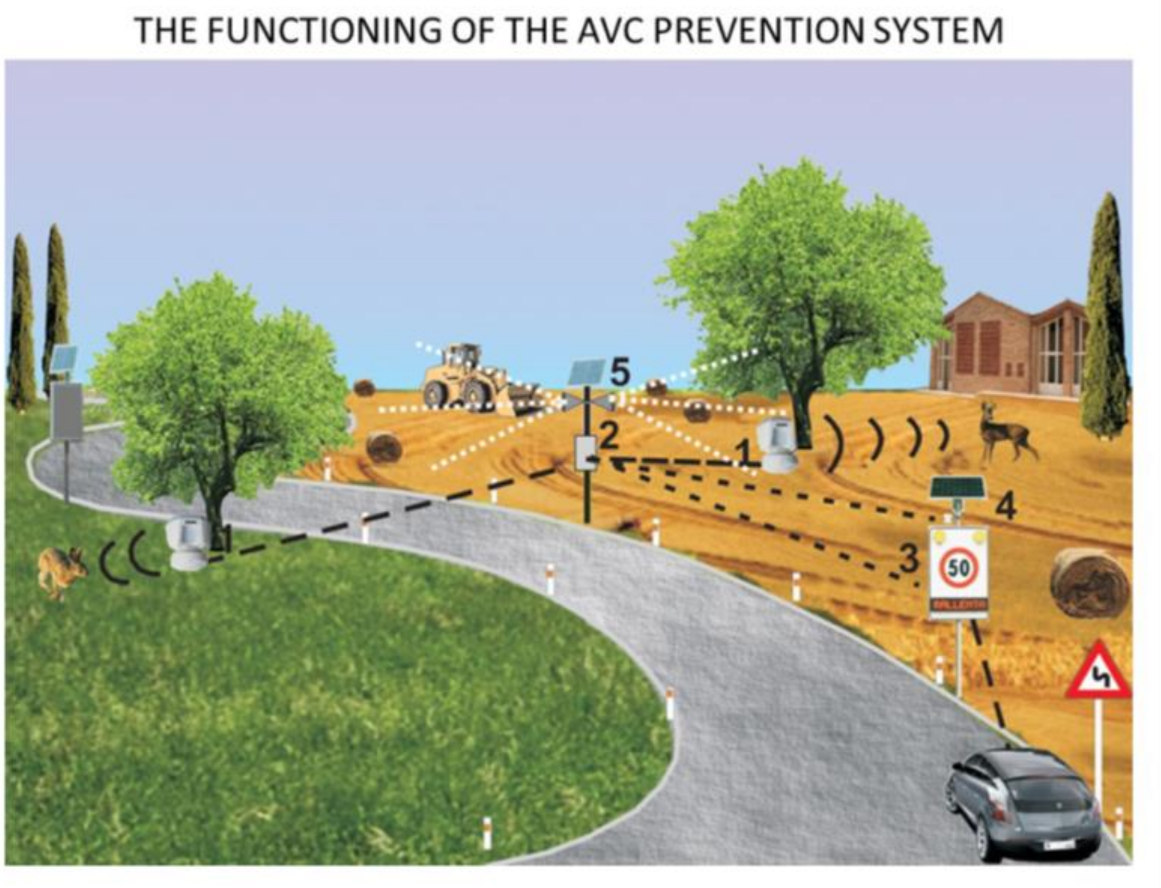

Figure 1. The AVC system

These systems already tested and operating in Italy under previous LIFE "STRADE" project are destinated to deter wildlife from crossing roads and at the same time to warn the approaching car/driver for an imminent wildlife crossing in order to slow down and avoid collision. This system aims at minimizing wildlife collisions with cars. In Greece the emphasis is put on brown bear (Ursus arctos) (target species) and it is expected to reduce the human caused mortality rates related to this cause (road mortality). To achieve these objectives three specific actions have been designed in the framework of the project, as follows:

Action A5. Description of target road segments, identification of crossing points used by animals and analysis of traffic volume and speed

Action C1. Installation of innovative AVC prevention systems and accompanying measures

Action D 1. Monitoring the impact of the concrete conservation actions (C Actions).

For the implementation of the above actions in Greece, the cooperation of two project actors has been foreseen, each of them dealing with a specific sub-task under action A5 distributed as follows:

(1) **CALLISTO NGO:** responsible for the implementation of action (A5) aiming at the precise designation of the (6) locations following systematic monitoring of (4) road segments of 37km total length and data analysis, for the installation of the AVC devices.

(2) **Region of Western Macedonia (RWM):** responsible for the implementation of action (C1): initiate and implement all the necessary steps regarding the public procurement and sub-contracting procedure for the purchase and installation of the (6) AVC's devices at the designated locations.

(3) **CALLISTO NGO + Region of Western Macedonia (RWM):** responsible for the implementation of action (D1): Monitoring of the operational phase and maintenance of the system at all (6) locations). Monitoring of the effectiveness of the AVC devices versus: (a) target species crossing behavior and reaction to the deterring effect of AVC's, (b) drivers' behavior in terms of vehicle speed, (c) overall wildlife and target species road mortality minimization. This will be achieved through: (a) analysis of activation data of the AVC Prevention System from data sent by the modem, (b) installation of camera traps near the AVC prevention systems in order to manage to observe if and how the animals react to the deterring effect of the AVC devices.

3.2 The Action A5.

Title of the Action A5: "Description of target road segments, identification of crossing points used by animals and analysis of traffic volume and speed".

The objective of this action is to identify the precise location of the sites where the AVC prevention devices will be installed and which have already been developed and tested at a certain scale in Italy in the frame of the previous LIFE STRADE Project. The implementation of action A5 along with the implementation of a specific methodological protocol, will also valorise the outcome from action A3 in which the broad conflict areas in terms of potential and/or effective road mortality risk have already been identified following data analyses from each partner country. Action (A5) is needed as a preparatory action for the plain implementation Action C1.

In Greece, in order to achieve actions (A5) implementation and objectives, the combination of (3) methods has been deployed as follows:

(a) in situ field investigations along each road segment- recording of different key variables such as: wildlife crossings (through biosigns detection), lands use, micro-landscape characteristics etc.

(b) Traffic volume and speed measurements: For each selected road segment regular measurements of traffic volume and vehicles speed using a specialized traffic and speed counter device with a rotation system to cover all road segments.

(c) Camera traps: In each road segment installation of camera traps to monitor wildlife movements at the selected crossing points at different seasons of the total monitoring period (12 months). The IR cameras have been systematically moved between potential/effective wildlife crossing points in order to select the ones most used by animals, with the aim to have more information to choose the best location where the AVC prevention systems will be installed.

Following the above steps and namely: (a) data entry, (b) data compilation of the gathered information from field surveys, traffic counter device and IR cameras, (c) digitized information layers regarding key environmental parameters, multivariate statistical analyses were performed in order to identify with the highest precision possible the (6) locations for the installation of the AVC's devices that will be realized under action C1.

The overall information has been stored according to a standardized form, and then transferred to a geographic database (Action A6), which will yield specific images that can then be used to study the most suitable sites for intervention and to obtain an index of permeability of the road segments

4. Study area

The study areas of the (4) monitored road segments (as described above) are located in North-western Greece in the Region of the Western Macedonia and in the two regional units: R.U. of Florina and Kastoria. The total length of all (4) monitored road segments is 37 km. It is worth noting that one of the initially chosen road segments and namely the one located along the old national road Siatista-Kastoria was judged not suitable for AVC installation as the presence of the bear proof fence of highway A29 that goes parallel along the one roadside of the old national road, would prevent wildlife from complete crossing and thus the AVC from being plainly effective.

The corridors in the immediate vicinity of the (4) monitored road segments is characterized by a relatively gentle relief of the semi-mountainous zone while the landscape shows strong mosaicism with main characteristics: crops, riparian forests and oak forests. In the wider eastern sector, the main feature of the landscape is the most intense relief of the southern ends of the mountain range of Peristeri (mts Vernon-Siniatsikon). In the study area the presence and activity of the bear is permanent throughout the annual cycle. It is worth noting that the project/study sub-area located in Florina RU is also part of the project area of the ongoing LIFE "AmyBear" project (LIFE15NAT/GR/001108). In the frame of the latter project and along the (2) road segments of the new and old national road a number of deterring and warning devices (such as WWR and acoustic reflectors (virtual fence) as well as signs for drivers) has been already installed.

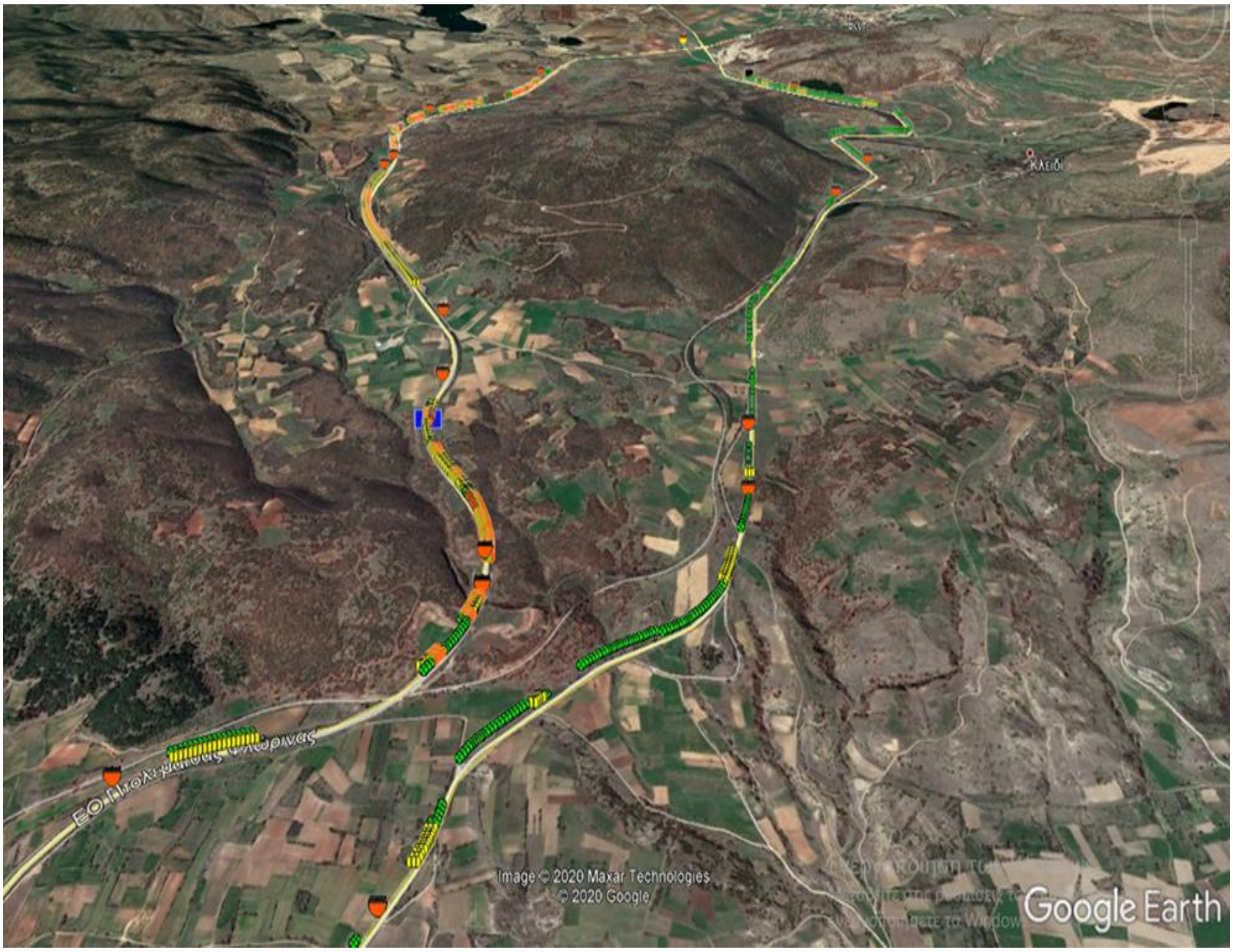

Figure 2. Alignment of the virtual fence and locations of signs for drivers (colourful dots) along the (2) segments of the new and old national road in Florina RU study sub-area.

Therefore, in this sector the selection of the (4) foreseen locations for the installation of the AVC devices has to take into account the pre-existing aforementioned deterring devices and to achieve the best possible combinatory effect between the three categories of devices as a synergistic result between the two projects.

In the project sub-area in Florina RU, and along the new and old national road targeted segments, sixteen (16) bear-car collisions (fatal for the bears) have occurred over the last 16 years whereas in the third monitored road segment in Florina RU (Pedino-Aetos- Agrapidies-Sklithro-Asprogeia) as well as in the fourth road segment in Kastoria RU ("Fotini – Metamorfosi") three (3) bear traffic fatalities (have occurred respectively in each road segment (total (6)) (in 2010, 2015 & 2018 and in 2013, 2015 & 2018).

5. Methods- Available field data

There are three sources of information regarding crossing locations. Bear telemetry data (collected in previous LIFE projects in the area), sign data (tracks) and camera trapping data.

Telemetry data are spatiotemporally very accurate and type and can provide unbiased information on bear habitat use and crossing frequency of tagged animals. However, with the exception of very few occasions it was not possible to know the exact crossing location of a specific road segment from tagged animals. In the other hand bear telemetry data are lacking those constraints related to sampling at detectability as- at least for the sampled period- tracking schedule is continuous and very dense. Few uncertainties occur considering unused or used areas and relocation of tagged animals is independent of the habitat type and mostly free of detection errors.

Data on crossing locations using signs (tracks of animals that cross the roads) in the other hand are difficult to obtain, they lack temporal precision, and may also suffer from heterogeneity in detection probabilities amongst different habitats and field conditions.

For example, it is difficult to locate mammal tracks in bushy or grassy habitat along roads. Moreover, weather conditions may seriously affect detectability of signs, e.g. after a heavy rainfall. However, the sign-track crossing data are spatially accurate which is their main advantage compared to telemetry data that provide only approximate crossing sites and can be easily implemented on long road stretches. Moreover, sampling refers to all the animals that cross the road network and not just a sample of them as with telemetry.

Camera trap data are spatially accurate and have several advantages compared to the other two methods. Apart from spatial accuracy the method can provide additional information regarding multispecies crossing frequencies, information on reproduction and population demographics. Detection probability for large mammal species, if cameras are set correctly and with caution is not seriously affected from environmental or weather conditions.

Table 1. Available field data used to estimate probability maps for collision risk zones

	Spring	Summer	Fall	Winter	Remarks-Use in analysis
Satellite telemetry data (4 bears)-General area	Sector I&II (May-2018). Project LIFE Amy Bear	Sector I&II (June-2018). Project LIFE Amy Bear	-	-	Four males. Habitat suitability maps & connectivity. Data weighted for sampling effort
Data across highways: Bear, wolf, wild boar, roe deer sign &crosses **Full length monitoring & evaluation**		Sector I: only new highway July 2018 Project LIFE Amy Bear	Sector I (2 reps, Oct, Nov-2017). Project LIFE Amy Bear	Sector I (1 rep, Dec 2017). Project LIFE Amy Bear	Estimated spatial distribution of crossing points-Probability crossing maps/risk collision. Data weighted for sampling effort
Data across highways: Bear, wolf, wild boar, roe deer sign &crosses **Selected segment monitoring & evaluation**	Sector I& II&III April 20	Sector I& II&III June 20	Sector I& II&III Aug 20	Sector I Nov19 Sector I& II&III Jan-Feb 20	
Camera trapping: Bear, wolf, wild boar, roe deer crosses **Selected segment monitoring & evaluation**	Old highway 2 cams New highway 7 cams Sklithro 5 cams Foteini 0 cams	Old highway 3 cams New highway 4 cams Sklithro 4 cams Foteini 1 cam	Old highway 2 cams New highway 3 cams Sklithro 1 cam Foteini 0 cam	Old highway 3 cams New highway 5 cams Sklithro 6 cams Foteini 3 cams	Estimate crossing frequency for selected crossing points
Bear accidents-data base[1]	ALL SEASON				All seasons data

Sector I: New and old highway, Sector II: Pedino-Aetos-Sklithro, Sector III: Foteini-Kastoria
Combination of telemetry and crossing data

[1] Psaralexi M., Mertzanis Y. (2020). Database for brown bear (Ursus arctos) vehicle collisions in Greece (Unpublished dataset). Aristotle University of Thessaloniki & Callisto. Last update 05/11/2020

5.1 Bear telemetry data

Four male bears were captured in late April 2018 in the study area and in the framework of the LIFE Amy Bear project. Unfortunately, all four animals dropped their collars in a relatively short time after their capture. Thus, we obtained data only from the period in-between 1/5/2018 to 26/6/2018. The same position acquisition schedule program was uploaded to all bear collars i.e., to take one location every 30 minutes

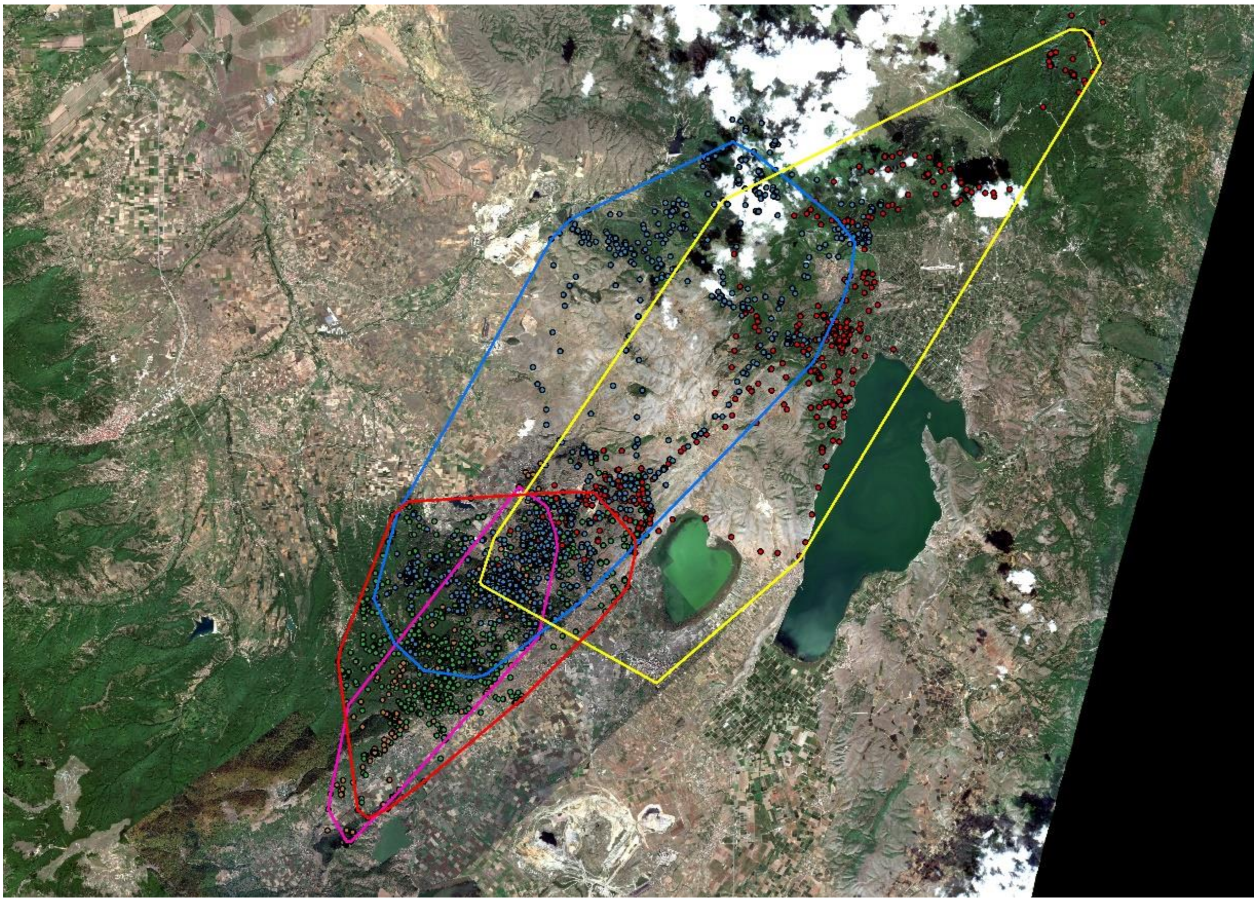

Figure 3, 95% MCP's of the 4 brown bears tracked in the study area.

All four bears crossed three of the four road segments under evaluation in a **total of 45 occasions.** As the old highway and the new highway road segments from Amydaio to Vevi are in close proximities and in parallel it was meaningful to compare crossing rates of bears

Table2. Telemetry data available for analysis

Bear ID-Name	Number of locations	Time period	MCP 95% area (km²)
Bear ID3839-Mousatos	920	7/5 – 27/5	58
Bear ID 6181-Markos	1881	15/5/ - 24/6	233
Bear ID 6182 - Ivo	1467	17/5 – 19/6	284
Bear ID 6183 - Liakos	2319	1/5 – 20/6	105

5.2 Road crossing data from ground surveys

Bear crossings were determined in the field by walking aside and close to the road verges and the surrounding area in a seasonal basis. Ten transect surveys were undertaken and all 4 road segments were sampled. Prior knowledge from 2018 surveys was used to plan for sampling effort during 2019 and 2020, thus sampling effort was more uniform in 2017-2018 while in 2019 and 2020, as transects were focused mainly on selected parts of the road segments under evaluation.

However as all transects were mapped with a handheld GPS device, heterogeneity in sampling intensity was taken account during analysis of the crossing data (i.e. a detailed bias file was used) and thus extrapolations and inferences were made possible for the whole length of the road segments under evaluation.

Table 3. Distribution of sampling effort per transect surveys.

Sample ID	Year	Season	Month	Length (meters)
1	2017	Autumn	10	28534
2	2017	Autumn	11	28836
3	2017	Winter	12	44010
4	2019	Autumn	11	4348
5	2019	Winter	12	4035
6	2020	Winter	1	2037
7	2020	Winter	2	2020
8	2020	Spring	4	23706
9	2020	Summer	6	5479
10	2020	Summer	8	1541
Total distance walked (km)				**138.46 km**

Detection probability for bear tracks was assumed homogenous amongst transects and areas because of the method used to determine crossings. Brown bear tracks are relatively easier to detect compared to other mammals due to their large size and can be visible even on dry and hard ground from experienced field personnel in a walking speed.

Inspection for bear tracks was not just a simple parallel walk aside road verges but included inspection of areas adjacent or even at distances of up to 200m from the road surface. Preferably only landscape patches which permitted easy imprinting of bear tracks were used for monitoring bear crossing sites. This was possible in the largest part of the road segments monitored due to the high percentage of agricultural land in the study area.

When bear tracks were discovered at a distance from the road surface, tracks were followed to conclude if the animal crossed the road or just used adjacent areas. The same procedure was followed for other species of large mammals (i.e. wild boar, roe deer, wolf). All tracks were mapped using a handheld GPS device (Garmin Map60c) and sampling effort (number of transect repetitions) was accurately defined for each road segment at intervals of 10 meters. Those data can be considered as "presence-no presence" data or more accurately "detection-non detection data".

Figure 4. Example of the transect survey method followed to locate bear crossings and reduce heterogeneity in detection probabilities during sampling. Transects were undertaken according to landscape features that increased detectability of bear tracks, like soft ground fields, ditch verges at distances of up to 200 m from the road line. When tracks were discovered they were followed to conclude if a crossing occurred or not. All fieldwork was conducted on foot to increase detection probabilities.

Table 4 . Field data summarized per category and species

Species /Category	Road crossings	Indices close to highway	Possible crossing	Probable crossing	Trainline crossing	Underpass crossing	Sum
Ursus arctos	176	47	1	3	1	2	**230**
Susus scrofa	76	43	2	13	2	1	**137**
Capreolus capreolus	12	6		3			**21**
Canis lupus	7	13	1	1		4	**26**
Other wildlife	85	8	16	6		3	**118**
Sum	**356**	**117**	**20**	**26**	**3**	**10**	**532**

Most bio-indices collected referred to brown bears and wild boar which were the most conspicuous species in the study area. 'Other wildlife" category included smaller mammals, unidentified wildlife and/or livestock. **Bear road crossings were verified in 176 cases.**

Although sampling was undertaken during all seasons of a biological year some road segments could be under or overrepresented during specific seasons. To overcome issues of uneven sampling effort a bias file was created to inform statistical software about the exact sampling effort per road segment with accuracy of 10m.

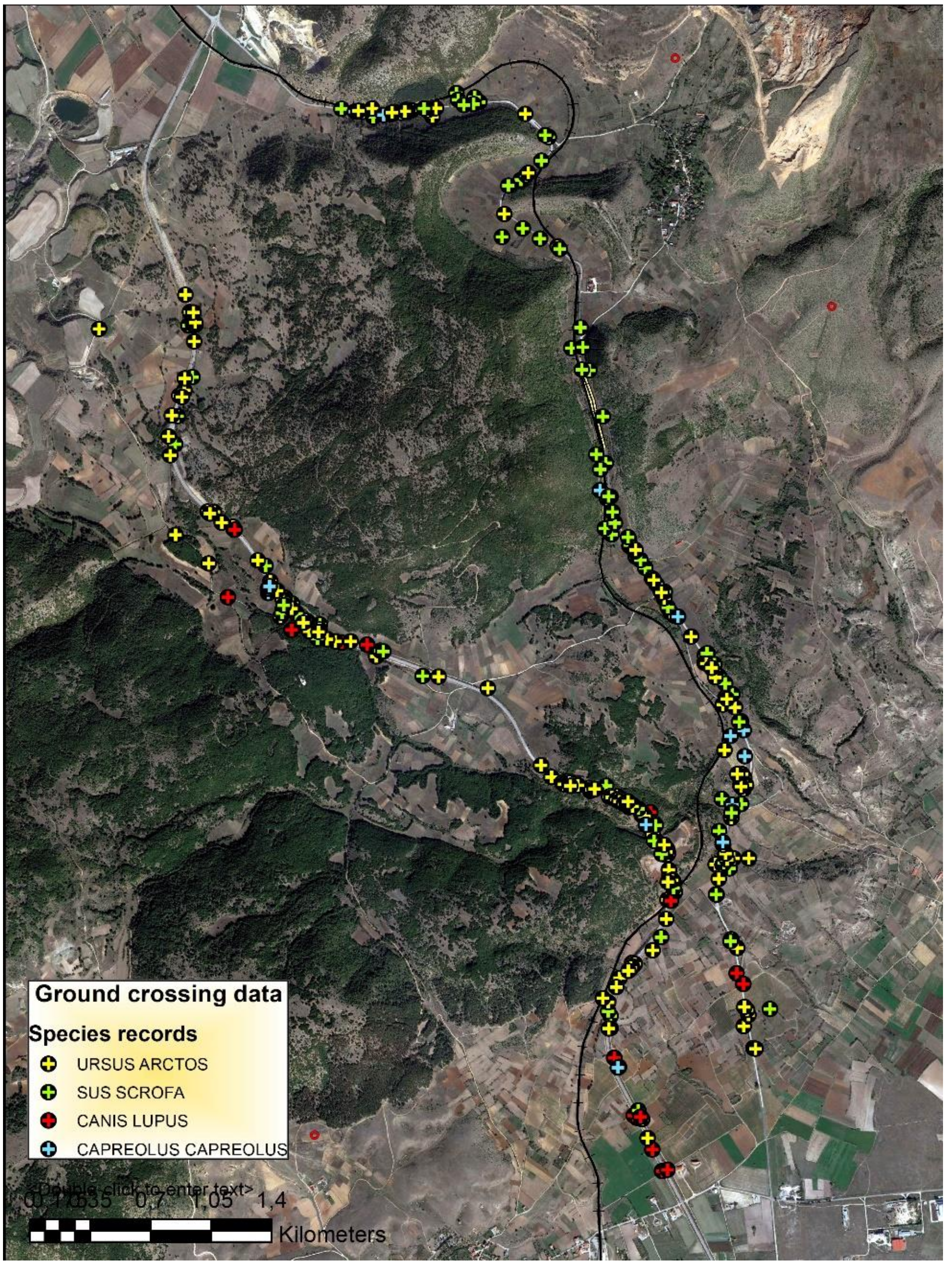

Figure 5. Distribution of large mammal species records (mainly tracks) close and over the **New and Old highway** from Amydaio to Vevi.

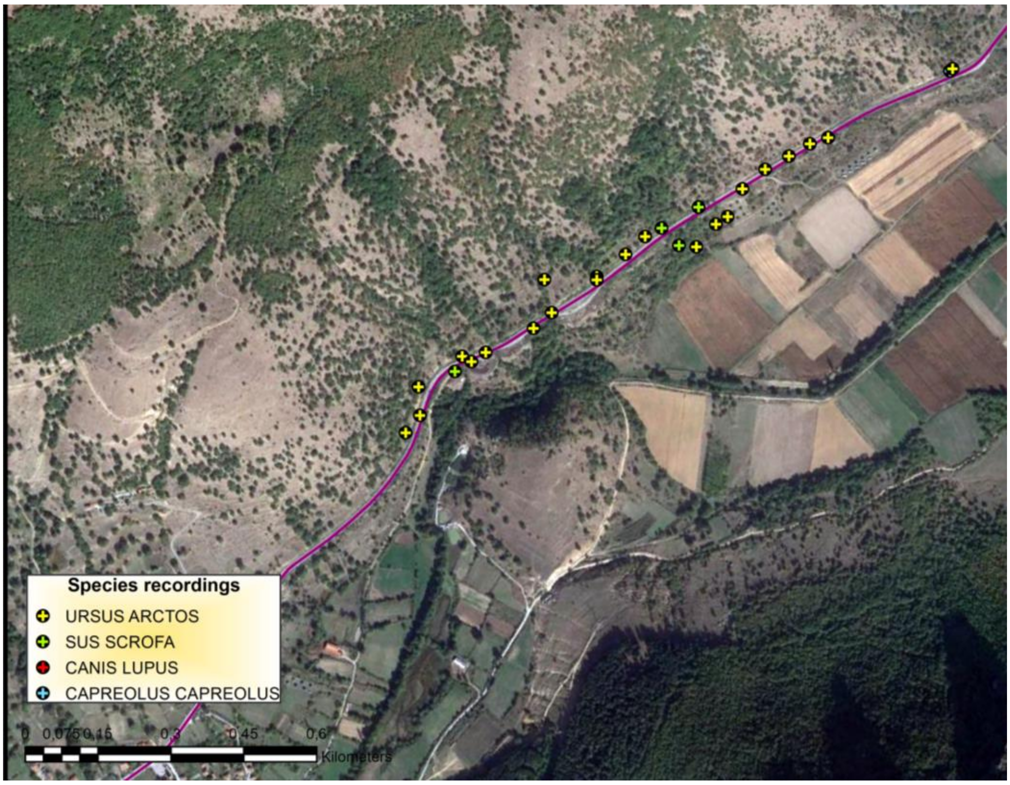

Figure 6 Distribution of species records (mainly tracks) close and over the **road segment from Aetos to Sklethro.**

Figure 7. Distribution of species records (mainly tracks) close and over the **road segment from Foteini to Metamorphosi.**

5.3 Camera trapping data

Camera trap data were used to define crossing frequencies of large mammals in selected areas according to field evidence and preliminary risk analysis to help select the final candidate locations for deployment of AVC's. Cameras were set in spots previously defined as possible crossing points for bears and other large mammals, in paths or small dirt roads leading and/or guiding animals to road segments studied. Thus, placement of the cameras was not random. As it was impossible to set cameras in all possible crossing locations, candidate camera positions were placed at those sites when:

a) Had a high probabilistic score in bear crossing and risk maps during preliminary analysis.

b) Field surveys revealed those points as wildlife crossing sites (e.g., there was a conspicuous path used by wildlife)

c) it was technically possible to set them safely in the field.

In total **36 cameras** were set in different locations from **15/11/2019 to 27/9/2020**.

Table 5 Distribution of camera trap effort amongst road segments under evaluation.

Road segment	Number of devices	Period	Trap nights activated
New highway from Amydaio-Vevi	15	16/11/2019-12/8/2020	710
OLd highway from Amydaio-Vevi	10	15/11/2019- 27/9/2020	752
Aetos Sklethro	7	21/1/2019-27/9/2020	773
Foteini-Metamorphosi	4	7/12/2019-12/8/2020	136
Total camera trap nights (actual activity)			**2371**

Camera traps recorded in total **501 events** with large mammals. Most of them corresponded to road crossing (n=398). Retreats and parallel walks accounted for the rest 103 cases.

Table 6. Camera records per species

	Behavior			
Species	**CROSS roads**	**PARALLEL WALK**	**COME AND RETURN**	Sums
URSUS ARCTOS	190	7	2	199
SUS SCROFA	115	41	9	165
CANIS LUPUS	58	10	2	70
CAPREOLUS CAPREOLUS	35	22	10	67
Sums	**398**	**80**	**23**	**501**

Table 7. Overall Performance (large mammals) of camera trapping per road segment

Species	SKLHTHRO	NEWHWY	OLDHWY	FOTEINH	Sums
URSUS ARCTOS	163	16	6	14	199
SUS SCROFA	7	97	61		165
CANIS LUPUS	49	6	7	8	70
CAPREOLUS CAPREOLUS	8	47	11	1	67
Sums	**227**	**166**	**85**	**23**	**501**
Trap nights	773	710	751	136	2371
RAI index pooled (recording per 100 days)	**29.36**	**23.38**	**11.31**	**16.9**	**21.13**

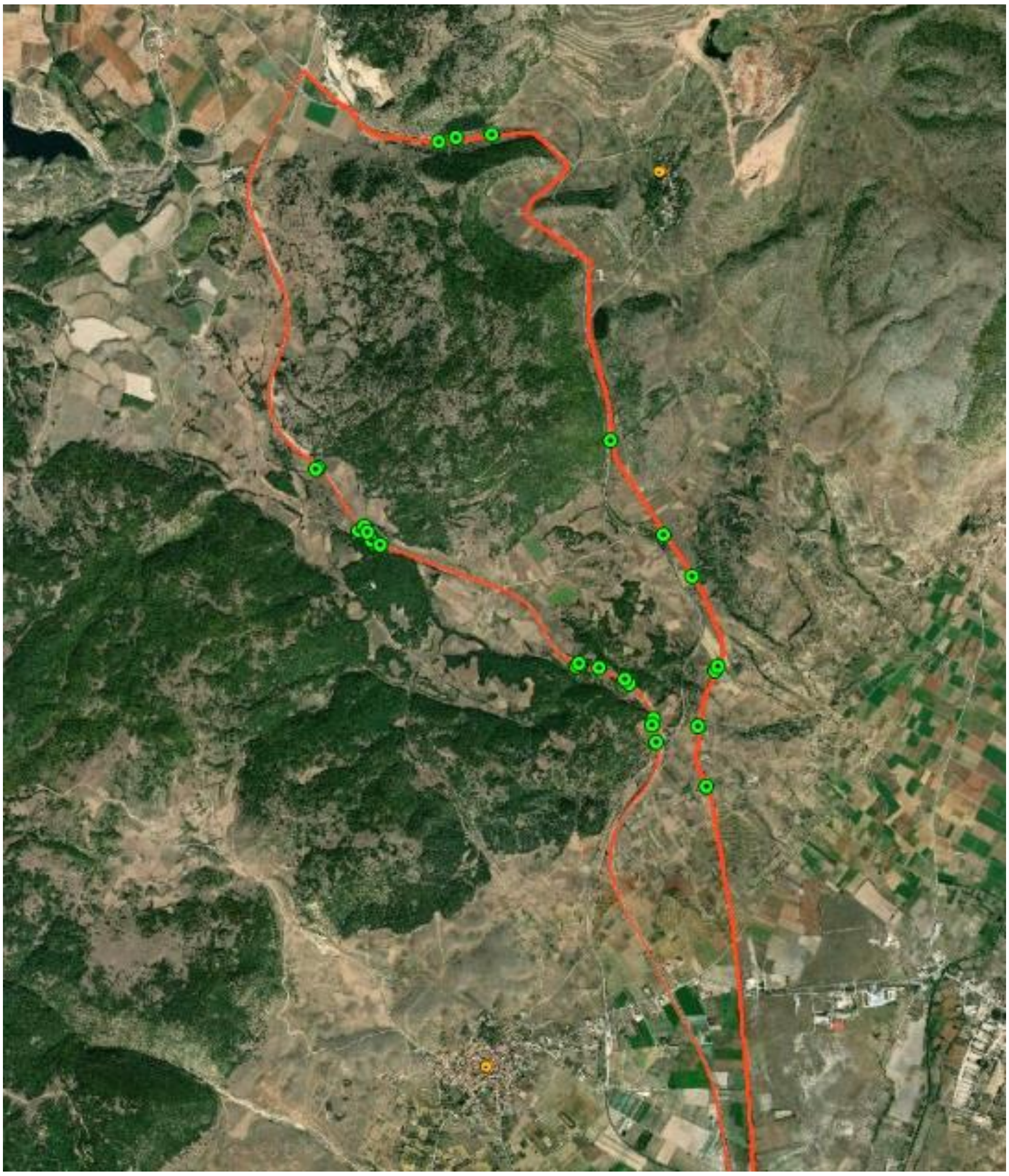

Figure 8. Hot spot camera trap positions (n=25) at the **New and Old highways** from Amydaio to Vevi.

Figure 9. Hot spot camera trap positions (n=7) in the **Aetos-Sklethro** road segment

Figure 10. Hot spot camera trap positions (n=4) in the **Foteini-Metamorphosi** road segment

For each camera trap or camera group we estimated the RAI index (RAI=eventsX100/total trap nights per camera or group) using only those events that **corresponded to crossings**. Apart from the number of events we also used and included in the analysis the **number of individuals** to account for group size as the collision risk will increase at higher absolute values of species abundance (i.e. RAI events and RAI population indices)

We estimated the **RAI index per species and** for all large mammals for each camera grouping (depending on their spatial association with candidate AVC positions)

AA	CAMERA TRAP CODE	GROUPAVCCAND	PATH	ROADSEGM	open	close	TRAPNIGHT	BEAR_EV	BEAR_POP	WOLF_EV	WOLF_POP	WBOAR_EV	WBOAR_POP	ROED_EV	ROED_POP	CRS_BEAR_EV	CRS_BEAR_POP	CRS_WOLF_EV	CRS_WOLF_POP	CRS_WBOAR_EV	CRS_WBOAR_POP	CRS_ROED_EV	CRS_ROED_POP
1	**AVCCAM01**	AV03	YES	OH	15/11/19	26/2/20	104	1	3	0	0	7	10	0	0	1	3	0	0	3	3	0	0
2	**AVCCAM02**	AV06	YES	OH	8/12/19	11/1/19	97	0	0	0	0	9	10	0	0	0	0	0	0	8	9	0	0
3	**AVCCAM03**	AV13	YES	NH	16/11/19	30/12/19	45	1	1	1	1	4	10	4	4	1	1	1	1	4	10	2	2
4	**AVCCAM04**	AV09	YES	NH	17/11/19	30/12/19	44	1	1	0	0	0	0	0	0	1	1	0	0	0	0		
5	**AVCCAM04B**	AV09	YES	NH	11/4/20	15/4/20	5	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
6	**AVCCAM05**	AV14	YES	NH	5/12/19	12/4/20	130	4	4	0	0	6	6	2	2	4	4	0	0	4	4	1	1
7	**AVCCAM07**	AV19	YES	FT	7/12/19	30/12/19	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	**AVCCAM08**	AV11	NO	NH	10/1/20	11/4/20	93	0	0	0	0	2	2	11	13	0	0	0	0	0	0	2	2
9	**AVCCAM08B**	AV11	YES	NH	11/4/20	24/5/20	43	0	0	0	0	5	13	0	0	0	0	0	0	4	12	0	0
10	**AVCCAM09**	AV02	YES	OH	11/1/20	30/4/20	111	1	1	4	5	2	2	0	0	1	1	4	5	2	2	0	0
11	**AVCCAM09B**	AV02	YES	OH	11/8/20	27/9/20	48	0	0	3	3	7	11	0	0	0	0	3	3	7	11	0	0
12	**AVCCAM10**	AV19	YES	FT	11/1/20	25/2/20	46	0	0	8	9	0	0	0	0	0	0	0	0	0	0	0	0
13	**AVCCAM11**	AV17	YES	SK	12/1/20	25/2/20	45	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0
14	**AVCCAM12**	AV17	YES	SK	12/1/20	10/4/20	152	45	48	6	6	2	2	0	0	43	46	6	6	2	2	0	0
15	**AVCCAM13**	AV16	YES	SK	28/1/20	12/8/20	197	38	42	1	2	2	2	2	2	35	39	1	2	1	1	2	2
16	**AVCCAM14**	AV16	YES	SK	28/1/20	15/5/20	108	10	10	1	1	2	2	0	0	9	9	1	1	1	1	0	0
17	**AVCCAM15**	AV15	YES	SK	29/1/20	12/8/20	178	34	36	7	13	1	1	6	6	34	36	7	13	1	1	6	6
18	**AVCCAM17**	AV18	YES	SK	25/2/20	10/4/20	46	2	3	0	0	0	0	0	0	2	3	0	0	0	0	0	0
19	**AVCCAM19**	NO	YES	OH	26/2/20	27/5/20	90	1	1	0	0	1	1	4	4	1	1	0	0	1	1	3	3
20	**AVCCAM20**	AV11	NO	NH	11/4/20	20/4/20	9	1	1	0	0	0	0	3	3	0	0	0	0	0	0	0	0
21	**AVCCAM21**	AV13	YES	NH	11/4/20	4/5/20	24	1	1	0	0	7	27	3	3	0	0	0	0	3	16	0	0
22	**AVCCAM22**	AV07	YES	NH	11/4/20	2/6/20	52	3	3	0	0	16	40	5	5	3	3	0	0	16	40	5	5
23	**AVCCAM22B**	AV07	YES	NH	11/6/20	21/9/20	103	1	1	3	4	37	176	7	7	0	0	1	1	24	106	3	3
24	**AVCCAM23**	AV08	YES	NH	13/4/20	14/6/20	62	4	4	1	1	13	20	11	12	3	3	0	0	1	1	2	2
25	**AVCCAM24**	AV05	YES	OH	14/4/20	11/8/20	119	1	1	0	0	30	114	5	5	1	1	0	0	29	109	5	5
26	**AVCCAM25**	AV04	YES	OH	12/6/20	11/8/20	61	2	2	0	0	0	0	0	0	2	2	0	0	0	0	0	0
27	**AVCCAM26**	AV06	YES	OH	12/6/20	11/8/20	61	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0
28	**AVCCAM27**	AV01	NO	OH	12/6/20	11/8/20	61	0	0	0	0	3	3	2	2	0	0	0	0	3	3	2	2
29	**AVCCAM28**	AV18	YES	SK	12/8/20	27/9/20	47	34	45	33	62	0	0	1		34	45	33	62	0	0	0	0
30	**AVCCAM29**	AV19	YES	FT	13/6/20	12/8/20	61	14	14	1	0	0	0	0	1	14	14	0	0	0	0	1	1
31	**AVCCAM30**	AV10	NO	NH	15/6/20	12/8/20	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	**AVCCAM32**	AV14	NO	NH	15/6/20	4/7/20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	**AVCCAM33**	AV13	NO	NH	15/6/20	4/7/20	20	0	0	0	1	7	29	0	0	0	0	0	0	0	0	0	0

Table 8. Detection history per species at camera traps in the study area. Cameras are also grouped in relation to AVC positions. Detections are expressed both as events and also as population (including number of animals detected per event. Cameras with zero detections or malfunctioned were omitted. Data were used to evaluate AVC candidate positions (see last chapter).

Adult bear heading to cross the Aetos -Sklethro segment in a highly-used wildlife crossing path (AVCCAM013)- over an embankment with low visibility to road surface

Adult male roe deer inspect traffic in the New highway segment before retreat (AVCCAM08) Roe deer appeared very alarmed close to highways in many cases and were reluctant to cross.

Wild boars carefully inspect highway prior crossing in a high-risk crossing point (New Highway, AVCCAM21). Wild boar mostly preferred trenches or flat areas at spots without guard rails to cross roads. Visibility is better in trenched areas rather in embankments where the collision risk was higher

A young wolf inspects traffic at a wildlife crossing path in the New Highway and then retreats. Crossing rates can be seriously affected by traffic volume. (AVCCAM22b)

5.4 Speed and traffic volume data

Vehicle speed and traffic volume is an important component for evaluating collision risks with wildlife. To collect relevant data a portable traffic counter was used to record traffic volume and record speed of passing vehicles in all 4 road segments under evaluation.

The VIACOUNT II device was set according to the manufacturer instructions. Preliminary tests in November 2019 showed that the device was able to accurately record traffic volume and vehicle speed only at the incoming traffic lane at up to 10meters form the road surface. So, for wider roads (i.e. the New highway from Amydaio to Vevi) the device was set at both lanes and the total traffic volume was assumed from both measurements. The device was functional only at straight segments of the road but not turns and it worked best when set at a height of 3.2 meters above road surface at approx. 3 meters from the edges of the nearest road verge.

A portable telescopic mount was especially designed and constructed during the project to facilitate measurements at this specific height. The mount was attached to guard rails when available. Alternatively, the VIACOUNT II device was also set and locked over powerlines beside road verges when prerequisites on proper distancing from road edges were kept. The device was able to record continuously for up to 15-20 days depending on ambient temperature that affected the battery life of the device.

Two recording sessions per road segment were undertaken (10 in total), one during summer or autumn months and the other during winter months. We used the same monitoring points and mounting installation protocol per road segment to minimize measurement bias. We used two counting points for the "New Highway" (Amydaio-Vevi), two counting points for the "Old highway" (Amydaio-Vevi), one counting point for the "Xino Nero-Aetos segment", one for "Aetos- Sklethro" segment and one for "Foreini-Metamorphosi" road segment,

Data were downloaded manually from the device, converted and stored in excel files.

Figures 11 Mounting of Viacount II device for traffic volume and speed metering in the new highway from "Amydaio to Vevi" by using a specially constructed mounting system (above) and in the "Old highway". When adjacent to the road power poles were available, they were also used to set the device at the appropriate height.

Traffic and speed data were averaged per road segment. A series of 7 traffic and speed metrics were calculated or derived directly from the ViaGraph software that supports the ViaCount II traffic counter.

1. **ADT- Average Traffic per day**: The average number of vehicles of all kinds that use the road daily in number of vehicles- Traffic volume
2. **Average Speed**: Average speed of all vehicle passes in Km/hr.
3. **Average Gap Time**: The average time between two subsequent vehicle passes in seconds. This metric was calculated only for incoming vehicles (only for a single lane) in the new highway but for both lanes in other segments. It is related to ADT and average speed
4. **Vmax, Maximum speed**: The average maximum speed detected per counting period in km /hr
5. **V85**: The average sequence speed percentile in the upper 15% percentile of the speed range, in Km/hr.
6. **P% >90**: The percentage of vehicles that exceeded speeds over 90km/hr (average value from counting periods)
7. **P% >100**: The percentage of vehicles that exceeded speeds over 100km/hr (average value from counting periods)

Table 9. Traffic and speed metrics for the road segments under evaluation.

	Foteini-Metamprphosi	**Aetos- Sklethro**	**Pedino-Aetos**	**Old highway Amydaio-Vevi**	**New highway Amydaio-Vevi**
ADT Traffic volume per day	*844*	*830*	*830 (727)*	*1200*	*2227*
Average speed in km/hr	*71*	*77*	*74*	*80.5*	*93*
Vmax, average maximum speed in km/hr.	*130*	*148*	*159*	*152*	*168*
Average gap time, sec	*129 (all)*	*129 (all)*	*121 (all)*	*103 (all)*	*30 (61 per lane)*
V85 average sequence speed percentile (km/hr.)	*84*	*92.5*	*94*	*94*	*110*
Percentage at speed >90 km/hr.	*7.44*	*18.68*	*19.36*	*22.45*	*55.16*
Percentage at speed >100 km/hr.	*0*	*6.26*	*7.76*	*7.31*	*31.93*
Road width in meters	*7*	*9*	*10*	*8*	*15*

6. Data analysis scheme- basic steps

1. **Analysis of telemetry data** (correspond to 45 crossings of 4 bears in May-June 2018):

Telemetry data were analyzed with MAXENT (presence - background data method) to create SDM (relative habitat suitability in the landscape spatial level (1000km2).

"Maxent, which stands for maximum entropy modelling, predicts species occurrences by finding the distribution that is most spread out, or closest to uniform, while considering the limits of the environmental variables of known locations. Maxent only uses presence data and the algorithm compares the locations of where a species has been found to all the environments that are available in the study region. It defines these available environments by sampling a large number of points throughout the study area, which are referred to as background points. Because background points can include locations where the species is known to occur, background points are not the same as pseudo-absence points"[2].

A Bias file was created according to the number of bears tracked per area weighted by the number of relocations per bear) as to provide the algorithm the information on which areas were surveyed and which were not. Mostly landscape variables were used. Standardized raw habitat suitability and logarithmic maps were produced. (Linkage analysis was after SDM distribution to derive a resistance map and design corridor for brown bear in the study area and define crossing probabilities over road segments under evaluation.

2. **Analysis of bear crossing points (correspond to approximately 180 crossings)**

Bear crossing data were also analyzed with MAXENT but only in the vicinity and around road segments (i.e. 20m). Landscape and other more related and specific to each road segment predictor variables were used too like vegetation at road verges, presence of barriers and forest roads. For each point of the road segments a sampling history was assigned and a detailed bias file was created to inform MAXENT about sampling intensity. The final output produces a gradient of road crossing probabilities along the road segments under evaluation.

3. **Combining of the two bear crossing models.**

Output for two bear crossing models (connectivity and ground models) were combined under certain weights after matching temporally the data or according to the number of crossings detected per season. Combined probability was used as a high information

[2] https://support.bccvl.org.au/support/solutions/articles/6000083216-maxent

variable (prior variable) to collision analysis as the sample size of accidents used was very small and only a few predictors could be used.

4. Risk collision model

A third Maxent model was run to define the probabilities and distribution of road accidents along the road segment under evaluation. The model uses prior information and data from traffic and characteristics of the road. No common variables were used between risk modelling and crossing models to avoid overfitting of the model.

5. Fine tuning with camera trap data and field observations

Camera trapping data (RAI indexes) and field data were used to fine tune information derived from models. Statistical modelling tries to imitate reality but not always with great success. Information on crossing frequencies from bears and other large mammals provided the information lacking from models (i.e. frequency of crossing) and thus can help prioritize important areas for conservation activities (i.e. installation of AVCs)

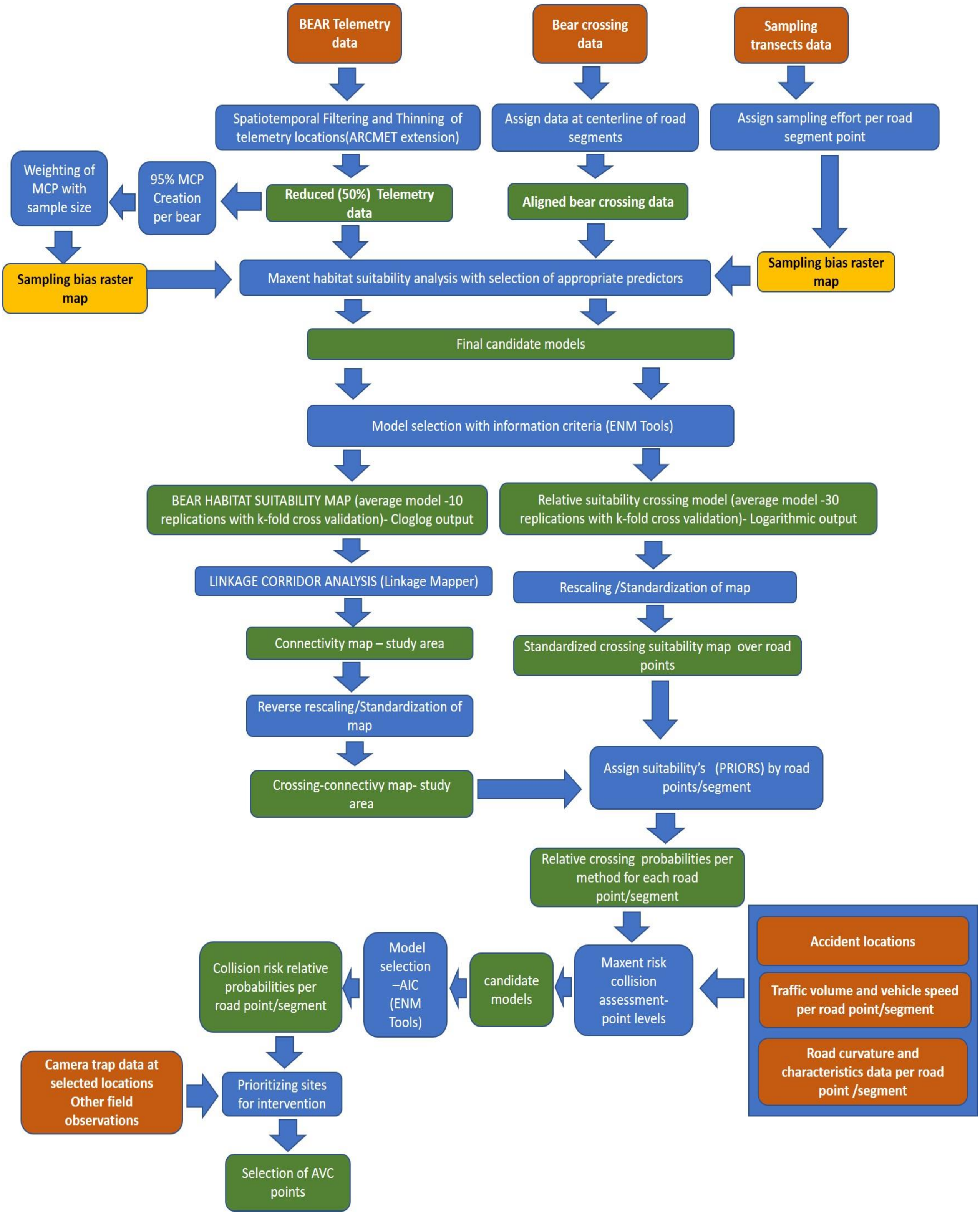

Figure 12. Analysis scheme chart followed for the selection of AVC sites. Brown blocks resemble data inputs, blue blocks analytical steps and green block output milestones. Bias files for Maxent analysis are resembled separately with orange blocks as they constitute a critical part of the analytical process.

7. Predictor variables used for statistical modelling and interpretation

Maxent telemetry	Maxent crossing	Maxent collision	Name	Type	Description (all raster's at 10X10m crid cell size)	Cell size resolution
x	x		DTM		Altitude	10
x	x		NVDI		NVDI index per each grid cell (10X10)	10
x	x		NVDI100		Average NVDI index at radius of 100m,	10
x	x		NVDI500		Average NVDI index at radius of 500m,	10
x	x		NVDI1000		Average NVDI index at radius of 1000m	10
x	x		VEGRASTER	Cat.	Forest maps	10
x			HWYDST		Distance from highways (New highway Amydaio-Florina, KA45) (meters)	10
x			PAVEDROADDST		Distance from all PAVED road network (meters)	10
x	x		FORESTROADDST		Distance from forest roads (meters)	10
x			ALLROADSDST		Distance from any road	10
x	x		ALLROADSDNS		Kernel Density of the overall road network (m/m^2). Default radius (3.177m)	25
x	x		VILLAGEDST		Distance from villages	10
x	x		FARMSDST		Distance from livestock farms	10
x	x		FARMDNS		Kernel Density of Farms Default radius (3.177m)	25
x	x		ASPECT	Cat.	Aspect	10
x	x		SLOPE		Slope	10
x	x		SLOPE100		Average slope at radius of 100m	10
x	x		SLOPE500		Average slope at radius of 500m	10
x	x		TRAINDST		Distance from trainline	10
x			FORESTSTAT	Cat.	NO forest, Deciduous forest, conifer forest	10
x			DSTTOFOREST		Distance from forest (m)	10
x	x		FORESTCOV100M		Forest cover at radius of 100m (number of cells with forest)	10
x	x		FORESTCOV500M		Forest cover at radius of 500m (number of cells with forest)	10
x	x		FORESTCOV1000M		Forest cover at radius of 1000m (number of cells with forest)	10
	x		FORKERNDST		Distance from nearest forest block (expressed as density at 50m radius using a value equal to the Euclidean distance from road to Forest)	10
	x		VOSKKERNDST		Distance from nearest natural grassland block (expressed as density at 50m radius using a value equal to the Euclidean distance from road to grassland)	10
	x		UNDERDST		Distance from bridges and other underpasses	10
	x		WATER		Distance from permanent water	10
	x		ALLBARNDST		Distance from supporting road walls/fences	10
	x		ALLBARDNS50		Kernel density of wall/fences at 50m radius	10

Maxent telemetry	Maxent crossing	Maxent collision	Name	Type	Description (all raster's at 10X10m crid cell size)	Cell size resolution
	x		ORYGDNS50		Kernel density of road trenches at 50m radius	10
	x		EMBDNS50		Kernel density of embarkments at 50m radius	10
	x		GUARDDNS50		Kernel density of guard rails at 50m radius	10
	x		VERGDNS20		Kernel density of vegetation patches at road verges up to 20m (at 50m radius)	10
		x	VERGDNS10		Kernel density of vegetation patches at road verges up to 10m (at 50m radius)	10
		x	CURVAKERNEL		Road curvature/turn angle deviation (value assigned to each point)	10
		x	CURVAVE50		Average curvature/turn angle at 50m (derived from Kernel density (at 50m radius)	10
		x	CURVAVE100		Average curvature/turn angle at 100m (derived from Kernel density (at 50m radius)	10
		x	CURVAVE200		Average curvature/turn angle at distance of 200m derived from Kernel density (at 50m radius)	10
		x	ADT		Daily average traffic volume per segment	10
		x	AVESPEED		Average vehicle speed per segment in Km/hr	10
		x	VMAX		Average maximum speed (km/hr)	10
		x	V85		Average sequence speed 85% percentile (km/hr.) per segment	10
		x	P>90		The percentage of vehicles that exceeded speeds over 90km/hr per segment (km/hr)	10
		x	P>100		The percentage of vehicles that exceeded speeds over 100km/hr per segment (km/hr)	10
		x	WIDTH		Road segment width in meters	10

All variables were calculated at a larger area than the study area used for analysis, as to permit buffering for those that encompassed averaging (i.e. NVDI, Forest Cover Slope) in certain radius (spatial scales). For GPS telemetry brown bear data with Maxent and subsequent connectivity analysis all raster variables were resampled from a 10m resolution grid to a 25m one as to **conform with the GPS telemetry acquisition error**. All other analysis (crossing analysis and collision risk analysis) used a 10m cell grid size (high resolution).

8. Creation of predictor layers (eco-geographical variables)

8.1 Vegetation map- NVDI indexed

Sentinel 2A multispectral satellite images were used[3] from a sentinel-2 satellite sensing at 13/9/2020 with **10X10m resolution**. The sentinel 2A package includes 12 monochromatic bands (Granules), one for each spectrum of visible or infrared light source.

Band	Resolution	Central Wavelength	Description
B1	60 m	443 nm	Ultra blue (Coastal and Aerosol)
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Visible and Near Infrared (VNIR)
B6	20 m	740 nm	Visible and Near Infrared (VNIR)
B7	20 m	783 nm	Visible and Near Infrared (VNIR)
B8	10 m	842 nm	Visible and Near Infrared (VNIR)
B8a	20 m	865 nm	Visible and Near Infrared (VNIR)
B9	60 m	940 nm	Short Wave Infrared (SWIR)
B10	60 m	1375 nm	Short Wave Infrared (SWIR)
B11	20 m	1610 nm	Short Wave Infrared (SWIR)
B12	20 m	2190 nm	Short Wave Infrared (SWIR)

To extract the NVDI index only two those bands are needed: the VIR/NIR infrared (visible to near infrared) granule and the red band granule. NVDI index was calculated according to the following formula[4] using the raster calculator tool (ArcGIS 10.3):

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

[3] https://scihub.copernicus.eu/dhus/#/home
[4] https://eos.com/ndvi/

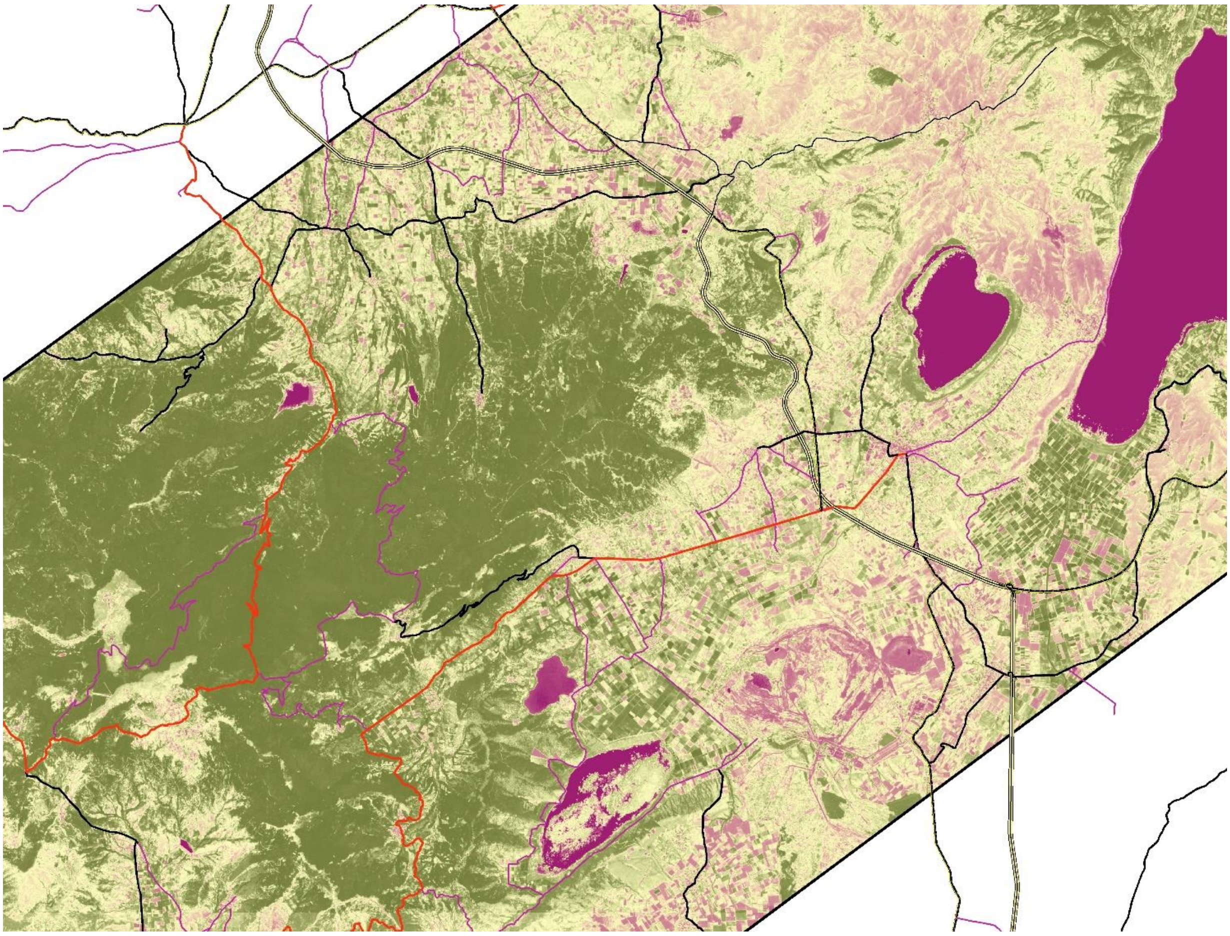

Figure 13. NVDI index calculation map in the northern part of the project area. Areas with highest NVDI numeric values appear green (forest and high productivity – irrigated agricultural areas)

8.2 Forest cover maps.

We used the Copernicus database[5] to download forest maps for the study area. Copernicus forest maps include only three vegetation classes: No forest (artificial landcover), deciduous forest, coniferous forests in a raster file with a resolution of 10m. We reclassified raster to have only 0 and 1 values (forest) and calculated the forest cover at each point of the study area surface at radiuses of 100, 500 and 1000m (spatial scaling) as the sum of forested cells (focal statistics).

8.3 Creation of hydrographic network – distance from water.

Creation of hydrographic network was achieved with the processing of DTM (digital elevation model). For classification of the derived hydrographic network the Strahler Sream

[5] https://land.copernicus.eu/pan-european/high-resolution-layers/forests/forest-type-1

Order method was used[6]. The relevant steps were implemented in ArcGIS by using the Spatial Analyst Hydrology tools with the following order:

Fill > Flow direction > Flow accumulation > Classification > Stream order > Raster to vector.

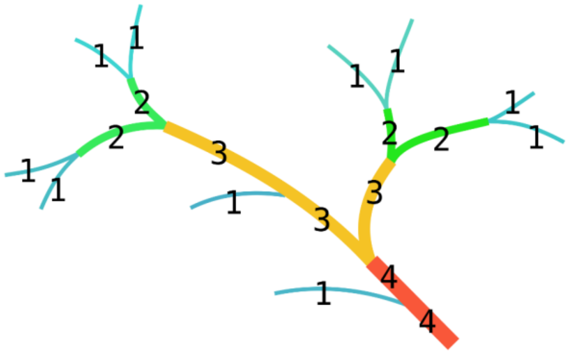

Figure 14[7]. Strahler Stream Order Classification. Streams of lower order joining a higher order stream do not change the order of the higher stream. Higher ordered streams have higher probability to maintain water year-round (perennial streams)

Apart from the creation of the hydrographic network permanent water sources, i.e., perennial streams, rivers and lakes were mapped and used as a separate layer. The Euclidean distance from water sources was calculated and a raster layer at 10m resolution was created.

8.4 Vegetation at verges of road segments.

This is an **important variable** and is related to both crossing rate probabilities and accident risk. Vegetation in the form of tree and scrub thickets can be used by wildlife as a temporal refuge just prior crossing a road and may be selected as such. Additionally, vegetation at verges can act as a visibility barrier reducing time for reaction simultaneously for both wildlife and drivers during a crossing event.

Tree and scrub thickets adjacent to road verges were digitized from Google earth maps approximately at a distance up to 100m. Thickets were classified in two classes depending on the lane they were closest to ("Right lane" and "left lane" verges). Distance from the center of each road segment at 10m intervals, within a radius less than 20m, was calculated from thickets present at both sites (near Tool, ArcGIS 10.3). A new attribute field was created and a value of 0 was assigned to each road segment point when no verges occur, a value of 1 when verges are present only in one lane, and a value of 2 when verges are present in

[6] Strahler, A. N. (1952). "Hypsometric (Area-Altitude) analysis of erosional topography". *Geological Society of America Bulletin* **63**: 1117–1142.
[7] https://en.wikipedia.org/wiki/Strahler_number

both lanes, at a distance **closer than 10 or 20 meters** from the center of the road (Near Tool threshold value).

Two kernel density raster layers for both distances were created by using as population field the number of verges present at those predefined distances per road segment point with a search radius of 50 meters. Both rasters were then extracted using a 20 m-width buffer mask around the centerline of the roads.

Figure 15. Mapping of vegetation thickets close to road verges in Aetos-Sklithro road segment

8.5 Road network

Road network including all types of roads was downloaded from Open street Maps site and georeferenced to the working layers (mapped from Google earth maps. However, it was largely incomplete. All forest roads were digitized from Google earth maps. Roads were then classified in three categories: Highways, paved roads (including highways) and forest roads.

8.6 Road Curvature at various scales

Curvature of a road segment can be an important predictor for collision risks, as it may affect speed of a vehicle (reduce at turns)) but also negatively affect visibility and consequently reaction time for both wildlife and drivers. As a measure of the road curvature, we considered the difference (deviation) of turn angles between two consecutive points in road segments evaluated, calculated with the use of the ArcVIew 3.2a extension "Path, with distances and bearings" v. 3.2b[8]. The resulting out is a point shapefile (10m interval)

[8] Jenness, J. 2007. Path, with distances and bearings (pathfind.avx) extension for ArcView 3.x, v. 3.2b. Jenness Enterprises. Available at http://www.jennessent.com/arcview/arcview_extensions.htm

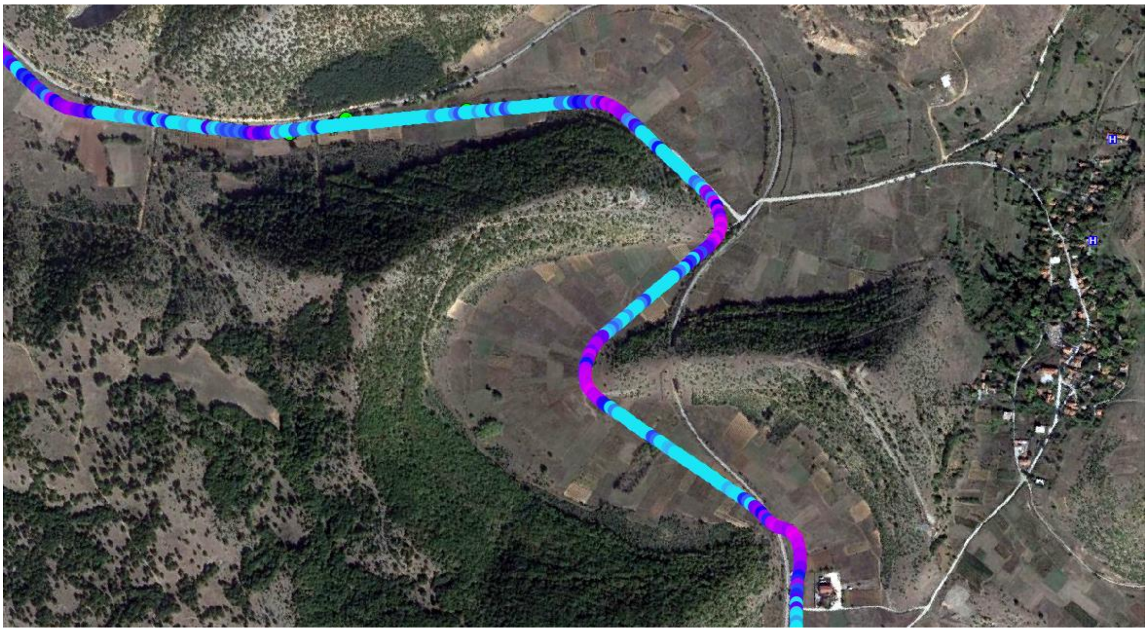

Figure 16. Curvature of a road segment in the study area (example from the old highway segment from Amydaio to Veve) calculated as the deviation between subsequent turn angles.

Then, a Kernel density raster was created with 5m resolution (5m cell size) at a radius of 50m from the road segment point and extracted with a buffer mask of 20 m around road points. Zonal statistics were used to calculate the average curvature at a radius of 50, 100, 200, 300 m from each point road segment (10m intervals). Values were assigned to each road point.

8.7 Guard rails, embankments and trenches.

All guard rails, embankments and trenches were mapped in the field and from Google earth maps. A kernel density raster was created for those variables to produce density predictor variables related to the presence of those road elements that may affect both crossing rates and also collision risk.

8.8 Road Barriers

All movement barriers (supporting walls and fences) close to roads were mapped in the field with a handheld GPS device and included in the analysis in the form of density and Euclidean distance maps.

9. Analysis of bear telemetry data

9.1 Creation of bias file for analysis of bear telemetry data with MAXENT.

MAXENT needs a bias file to operate correctly that shows the software which areas were actively monitored during the survey period. This is a critical step proposed in studies dealing with MAXENT accuracy and adjustment of MAXENT inputs[9],[10]. Bias files should be in the form of raster files (ascii files) with the same resolution (cell size), extent and geographical coordinate system as the environmental layers.

Sampling effort was estimated in the base of how many bears were tracked in a specific area according to the distribution of MCP polygons and their relative importance according to the number of relocations per bear, which is analogous to the duration of the monitoring for each bear.

To achieve this, the following steps were undertaken.

For each one of the brown bears tracked (n=4) a minimum convex Polygon (95% MCP) was estimated with the use of the ArcGIS extension ARCMET 10.2.2 V3.

To deal with different sample size of relocations per bear tracked a special weight was assigned to each MCP polygon which was the proportion (range: 0- 1) of the pooled sample of all bear relocations (i.e. Liakos (n=2319), Ivo (n=1467), Markos (n=1881), Mousatos (n=920) with corresponding weights: WL = 0.35, WI=0.22, Wma=0.285, Wmou=0.14.

Then, all the MCP polygon files were merged to create a single multipart shapefile (Union tool, ESRI ArcGis 10.3). For each one of the parts created -following polygon intersections - the weights of the different bears were assigned by joining the union feature with itself ("spatial join analysis" selecting as join operator the "join one to many" option), thus creating a multi-record attribute table.

Then, the spatial join feature was unified again by dissolving the multi-record feature according to the target FID of each part, while a final weight was calculated and assigned

[9] Kramer-Schadt, Stephanie & Niedballa, Jürgen & Pilgrim, John & Schröder, Boris & Lindenborn, Jana & Reinfelder, Vanessa & Stillfried, M. & Heckmann, Ilja & Scharf, Anne & Augeri, D. & Cheyne, Susan & Hearn, Andrew & Ross, Joanna & Macdonald, David & Mathai, John & Eaton, James & Marshall, Andrew & Semiadi, Gono & Rustam, Rustam & Wilting, Andreas. (2013). The importance of correcting for sampling bias in MaxEnt species distribution models. Diversity and Distributions. 19. 1366-1379. 10.1111/ddi.12096.

[10] Merow, Cory & Smith, Matthew & Silander, John. (2013). A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. Ecography. 36. 10.1111/j.1600-0587.2013.07872.x.

for each part as the sum of bear weights overlapping (Dissolve tool with statistics field active: sum of weight).

The final-weight maximum value was 1 (i.e. when all bears were present in a particular part) and the lower was 0.14 (only the bear with the lowest weigh was present), while for the rest of the area, where no bear were tracked, this value equaled 0.

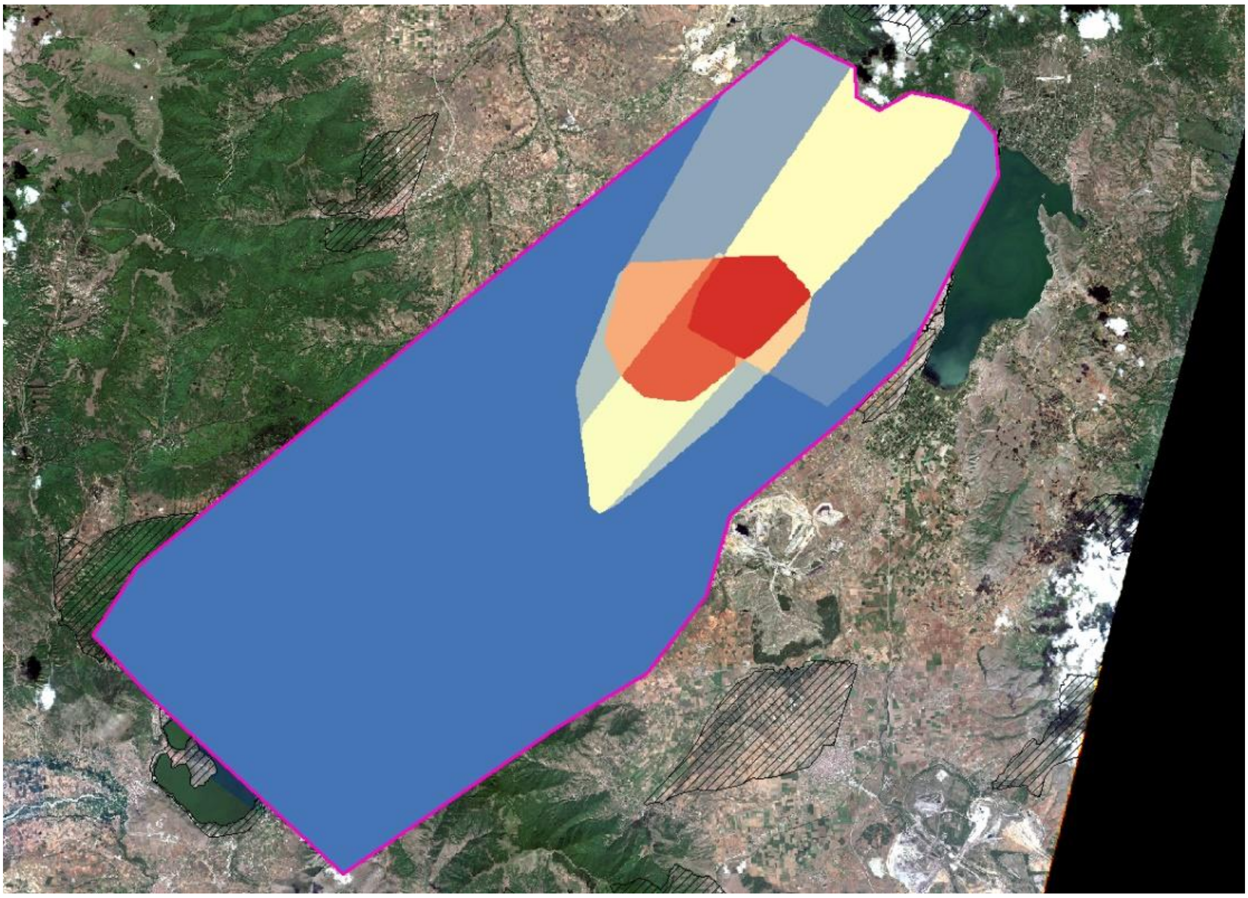

Figure 17. Bias raster file used for analysis of brown bear telemetry data weighted according to the proportion of relocations per bear. The raster takes a value between 0-1.

The feature shapefile was then converted to a raster file (10X10m grid cell size) and merged with a similar cell-sized raster layer which was given the value of 0 in areas where no bears were tracked. The two raster files were merged with "the mosaic to new raster" tool using as a mosaic operator the option "sum".

The final bias raster file has a value ranging from 0 to 1 according to the number of bears tracked in each one cell and their respective sum of weights according to the overall sampling effort (number of relocations). Zero values were replaced with the 1^{-23} value as Maxent does not accept zero values for the bias file

We used as a **background area** for MAXENT analysis the whole study area as it is included in the known distribution of brown bear according to previous preliminary field surveys.

9.2 Selection of bear telemetry locations for analysis- Filtering and thinning of GPS data.

Although a bias file was created resembling spatiotemporal sampling intensity related to bear telemetry based on the 95%MCP's, we also reduced spatial autocorrelation within the data by filtering and thinning as the number of locations can affect Maxent outputs[11]. Moreover, reducing the amount of spatial autocorrelation amongst data produces less overfitted results and more realistic suitability prediction maps[12].

This was achieved by using three **spatiotemporal segregation criteria** amongst subsequent locations: Bear speed (km/hr), area covered (in meters) and time interval in-between subsequent locations.

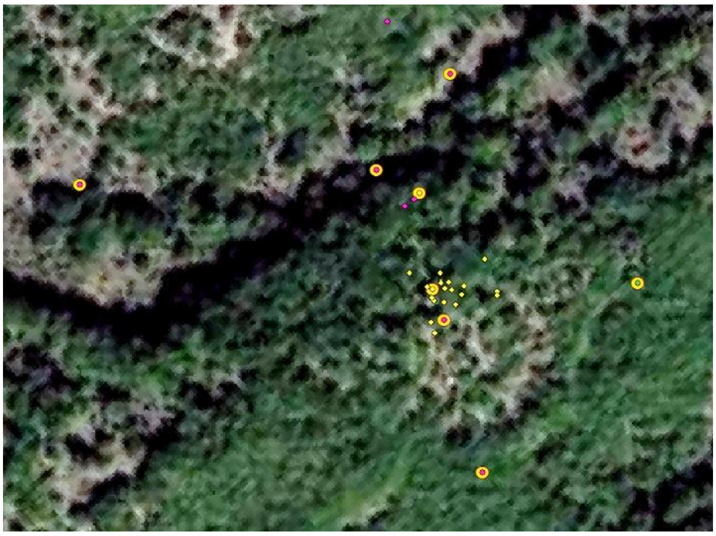

Figure 18. Effects of bear telemetry data thinning according to spatiotemporal criteria. Only one location is retained in the data set per GPS cluster, bear and 24hr period

(After testing several scenarios, we finally selected for analysis only those locations related to bear movements with a length above 50m, bear speed of more than 0.5 kms/hr in between subsequent locations.

In this way clusters of bear relocations related to resting or foraging were represented in the analysis with only one location for each day (24hr period), GPS location cluster and individual bear.

Thus, weights for **different types of bear activity were homogenized**, i.e. both movement and resting/foraging are equally represented in the data set). Thinning of the overall data was substantial as from the initial data comprised of 5775 locations a total of 2261 locations were finally retained.

Data filtering was undertaken **separately for each** one of the 4 bears tracked and the filtered data sets were then merged in a single file. We used only one pooled data set because it resembled a single season of bear monitoring, while differences in sample size per bear was accounted with the use of a bias file.

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[11] Wisz, M. et al. 2008. Modelling pink-footed goose (Answer brachyrhynchus) wintering distributions for the year 2050:
potential effects of land-use change in Europe. Divers. Distrib. 14: 721,731
[12] Radosavljevic, A. and Anderson, R.P. (2014), Making better Maxent models of species distributions: complexity, overfitting and evaluation. J. Biogeogr., 41: 629-643. https://doi.org/10.1111/jbi.12227

9.3 Variable correlation Matrix (telemetry analysis)

Variables (predictors of habitat suitability) should not be correlated otherwise model outputs produced in MAXENT (or any kind of species distribution models) can be overfitted and not valid. Thus, we created a correlation matrix to avoid the simultaneous inclusion in the models of predictors with more than a Pearson R value of 0.65. Pearson coefficients greater than 0.65 are marked with red captions.

Table 10. Correlation matrix for predictors used in MAXENT 3.4.1 for analyzing telemetry locations

	ALLROADDST	ALT	FARMDNS	FARMDST	FORROADSDST	NHWYDST	NVDI1000	NVDI100	NVDI	NVDI500	POWERDST	ROADDNS	SLOPE100	SLOPE	SLOPE500	TRAINDST	VILLAGEDST
ALLROADDST	**1,00**	0,16	-0,20	0,16	0,80	0,07	-0,23	-0,21	-0,19	-0,24	0,34	-0,46	0,11	0,10	0,26	0,08	0,15
ALT	0,16	**1,00**	-0,36	0,45	0,07	0,59	0,54	0,45	0,41	0,50	0,27	-0,48	0,57	0,51	0,27	0,32	1,00
FARMDNS	-0,20	-0,36	**1,00**	-0,65	-0,21	-0,29	-0,15	-0,13	-0,12	-0,15	-0,23	0,40	-0,22	-0,20	-0,28	-0,29	-0,36
FARMDST	0,16	0,45	-0,65	**1,00**	0,14	0,23	0,22	0,19	0,17	0,21	0,26	-0,33	0,25	0,23	0,40	0,11	0,46
FORROADSDST	0,80	0,07	-0,21	0,14	**1,00**	0,07	-0,27	-0,24	-0,22	-0,26	0,09	-0,45	0,12	0,10	0,25	0,08	0,07
NHWYDST	0,07	0,59	-0,29	0,23	0,07	**1,00**	0,43	0,36	0,33	0,40	0,05	-0,34	0,49	0,44	0,07	0,57	0,60
NVDI1000	-0,23	0,54	-0,15	0,22	-0,27	0,43	**1,00**	0,89	0,81	0,97	0,03	-0,04	0,44	0,40	0,08	0,13	0,55
NVDI100	-0,21	0,45	-0,13	0,19	-0,24	0,36	0,89	**1,00**	0,94	0,94	0,02	-0,03	0,43	0,39	0,08	0,10	0,46
NVDI	-0,19	0,41	-0,12	0,17	-0,22	0,33	0,81	0,94	**1,00**	0,86	0,02	-0,02	0,39	0,36	0,07	0,09	0,42
NVDI500	-0,24	0,50	-0,15	0,21	-0,26	0,40	0,97	0,94	0,86	**1,00**	0,03	-0,03	0,44	0,40	0,08	0,11	0,51
POWERDST	0,34	0,27	-0,23	0,26	0,09	0,05	0,03	0,02	0,02	0,03	**1,00**	-0,45	0,13	0,12	0,53	-0,04	0,27
ROADDNS	-0,46	-0,48	0,40	-0,33	-0,45	-0,34	-0,04	-0,03	-0,02	-0,03	-0,45	**1,00**	-0,38	-0,34	-0,49	-0,06	-0,48
SLOPE100	0,11	0,57	-0,22	0,25	0,12	0,49	0,44	0,43	0,39	0,44	0,13	-0,38	**1,00**	0,95	0,15	0,26	0,57
SLOPE	0,10	0,51	-0,20	0,23	0,10	0,44	0,40	0,39	0,36	0,40	0,12	-0,34	0,95	**1,00**	0,13	0,24	0,52
SLOPE500	0,26	0,27	-0,28	0,40	0,25	0,07	0,08	0,08	0,07	0,08	0,53	-0,49	0,15	0,13	**1,00**	-0,20	0,27
TRAINDST	0,08	0,32	-0,29	0,11	0,08	0,57	0,13	0,10	0,09	0,11	-0,04	-0,06	0,26	0,24	-0,20	**1,00**	0,33
VILLAGEDST	0,15	1,00	-0,36	0,46	0,07	0,60	0,55	0,46	0,42	0,51	0,27	-0,48	0,57	0,52	0,27	0,33	**1,00**

9.4 MAXENT run for brown bear telemetry data- Parametrization and results

MAXENT allows the user to define several parameters that affect the analysis and may produce a variety of results according to specific parametrization each time, like type of validation procedures including separation of the data into training and test sets or replication with several types (cross validation, bootstrap, subsampled), selection of a regularization multiplier (affects beta coefficients of variables), number of iterations and type of features.

There are several validation criteria produced by the analysis including: AUC estimation (area under the ROC curve), analysis of omission -commission, percent contribution and permutation importance of variables, jackknife tests of variable importance, suitability maps and response curves per variable examined in the models.

We included all feature types available (linear, quadratic, product, hinge), with a **5000-iteration** threshold, using **10 replicates per run** with the random seed selection (different combinations of training and test set for each run) and **removal of duplicate presence points** in cells (to further reduce autocorrelation of data).

We selected for the **cross validation** run type of replication as suggested from several authors especially when for large amount of presence points is used for analysis (telemetry data) like in our case. Prevalence was kept at the default value of 0,5 as the species is a common generalist species[13] and is known to be present in the whole study area.

We selected the Clog-log output which compared to the log output, as areas of moderately high output are more strongly predicted and highlighted[14], as we need to define bear habitat core areas prior running connectivity analysis.

Predictors related to the technical characteristics of the roads like embankment density, ditch density, distance and density of potential barrier over roads were not used at this level of analysis as those expect to have an influence at closer distances to the road segments.

A stepwise forward procedure was used to build the models. Fist, the Maxent algorithm was run a series of univariate models for each one of all predictor variables. The best (highest AUC value) univariate (single variable) model was set as the baseline model. We gradually added all variables one by one and excluded those that could reduce the overall training and test gains compromising the predictive value of the model. We dropped

Variables were maintained in the model under certain criteria:

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[13] Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. and Yates, C.J. (2011), A statistical explanation of MaxEnt for ecologists. Diversity and Distributions, 17: 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

[14] Phillips, S.J., Anderson, R.P., Dudík, M., Schapire, R.E. and Blair, M.E. (2017), Opening the black box: an open-source release of Maxent. Ecography, 40: 887-893. https://doi.org/10.1111/ecog.03049

a) No drop of test AUC value was observed- an increased AUC value was desired instead,

b) Predictor variables in the model achieved individual model gains not higher than the overall model gain, both for the regularized training set and the test set,

c) Each predictor variables achieves alone a higher test AUC than the over test AUC of the model.

We also experimented with four different **regularization b-multipliers** (0.1, 0.25, 0.75, 1) for each model and observed changes in distribution maps (logistic and raw format). Larger values of regularization multipliers than the default value (1), produced smoother species distribution and avoid overfitting of the models and thus they are recommended from some authors [15] for mapping species distributions in large areas. However, we choose instead to experiment with those lower values compare to default values in that specific analysis to achieve a higher level of spatial accuracy in habitat selection according to the research question at hand (i.e. crossing areas at roads).

Bears are generalist species at our goal was to produce suitability maps with higher spatial resolution and detail, and less coarse, than in for example when large scale distributions are drawn with SDM's (Species distribution models). Nevertheless, reduction of the regularization parameters affected only slightly AUC values (index of model discriminatory ability) thus we did not separately test those models. Instead, **we selected the 0.25 b- multiplier as the default for all final candidate models.**

The final set of candidate models had the highest possible test AUC value from all combinations tested. To select the most suitable model we used an independent analysis (ENM Tools) especially designed to select the best model amongst several candidate output models from the MAXENT using information criteria.

9.5 Bear telemetry model selection

We used ENM Tools v.13[16] which is an especially designed algorithm to analyze maxent outputs to select amongst the five candidate models. This function allows criterion-based model selection using AIC, AICc, and BIC (Warren and Seifert 2011[17], Burnham and Anderson

[15] Radosavljevic, A. and Anderson, R.P. (2014), Making better Maxent models of species distributions: complexity, overfitting and evaluation. J. Biogeogr., 41: 629-643. https://doi.org/10.1111/jbi.12227

[16] Warren, D.L., R. E. Glor, and M. Turelli. 2008. Environmental niche equivalency versus conservatism: quantitative approaches to niche evolution. Evolution 62:2868-2883

[17] Warren, D.L., and S.N. Seifert.. Environmental niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications. (doi: 10.1890/10-1171.1)

2002[18]). When this function is selected, ENMTools asks for a script file containing ASCII raster files and lambdas files, provided by MAXENT outputs, for the models being compared, along with .csv files of occurrences. Warren and Seifert propose AIC as the most suitable diagnostic for large data sets and AICc for smaller samples for best model selection. BIC criterion penalizes for model parameters and is depended on the number of predictor variables used.

Table 11, Model selection. Variables used in the top candidate models

	MODEL 1	**MODEL 2**	**MODEL 3**	**MODEL 4**	**MODEL 5**	**MODEL 6**	**MODEL 7**	**MODEL 8**	**MODEL 9**	**MODEL 10**
allroadsdst	x					x				
alt	x	x	x	x	x	x	x	x	x	x
aspect	x	x	x	x	x	x	x	x	x	x
Dst forest	x		x							
Forest cat	x	x	x	x	x	x	x		x	x
Forest Cov100	x	x	x	x	x	x	x		x	
Nvdi							x			
Nvdi100								x	x	x
Paveddst	x	x	x	x	x	x	x	x	x	x
Roaddns	x	x	x	x	x	x	x	x	x	x
Slope 100	x	x	x	x	x	x	x	x	x	x
Vegraster	x	x	x	x	x	x	x	x	x	x
Training set **AUC value**	**0.774**	**0.772**	**0.768**	**0.765**	**0.765**	**0.770**	**0.765**	**0.766**	**0.764**	**0.764**
Test set **AUC value**	**0.757**	**0.757**	**0.751**	**0.748**	**0.748**	**0.753**	**0.747**	**0.744**	**0.745**	**0.742**

[18] Burnham, K. P., and D. R. Anderson, 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag. ISBN 0-387-95364-7.

Table 12. ENM Tools diagnostics for the top candidate models

Model name	Log Likelihood	Parameters	Sample Size	AIC score	AICc score	BIC score	Model code
Model 1	**-309.273**	**188**	**2260**	**622.306**	**622.649**	**633.066**	**T8**
Model 2	-310.073	115	2260	622.447	622.571	629.028	T3
Model 3	-309.842	160	2260	622.885	623.130	632.042	T20
Model 4	-310.333	135	2260	623.367	623.540	631.094	T1
Model 5	-310.333	135	2260	623.367	623.540	631.094	T19
Model 6	-309.925	176	2260	623.370	623.669	633.442	T5
Model 7	-310.336	161	2260	623.892	624.141	633.107	T14
Model 8	-310.701	148	2260	624.362	624.571	632.832	T18
Model 9	-310.572	173	2260	624.604	624.893	634.505	T16
Model 10	-310.797	172	2260	625.035	625.320	634.878	T17

The "best" model had the lowest Log Likelihood, and AIC (and AICc) score (Akaike information criterion) compared to the rest of the candidate models, but the BIC (Bayesian information criterion) value was not the lowest as the model used more predictor parameters than the other models. BIC penalizes for additional parameters in a model. We recorded low heterogeneity in the top candidate models (very low differences in AIC values and few differences in type of predictors used) so we did not averaged models. The "best" model was run under a 0.25 regularization multiplier, included seven (10) out of the 21 environmental variables initially tested, and achieved an average test AUC for the replicate runs of 0.757 with a standard deviation of 0.008. We validated model with a 10-fold cross validation with enabled random seed.

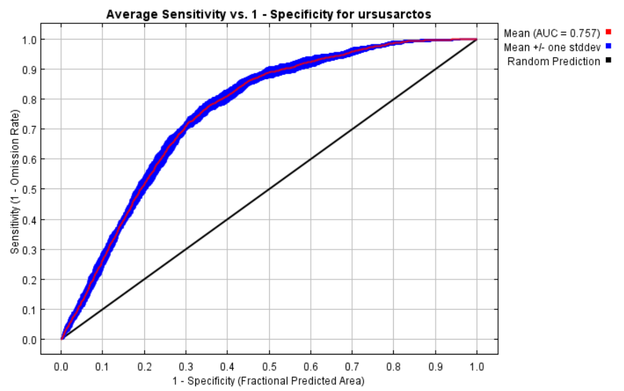


Figure 19. Average AUC value of the selected model after 10 replications.

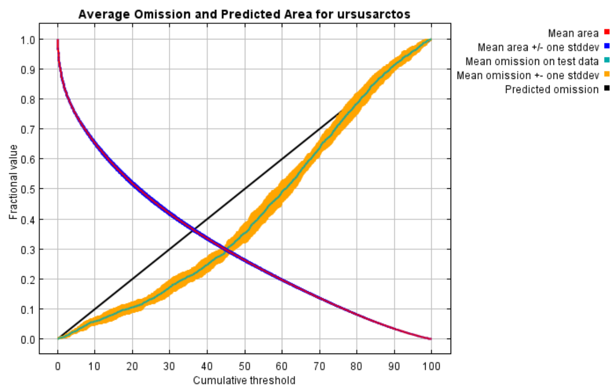
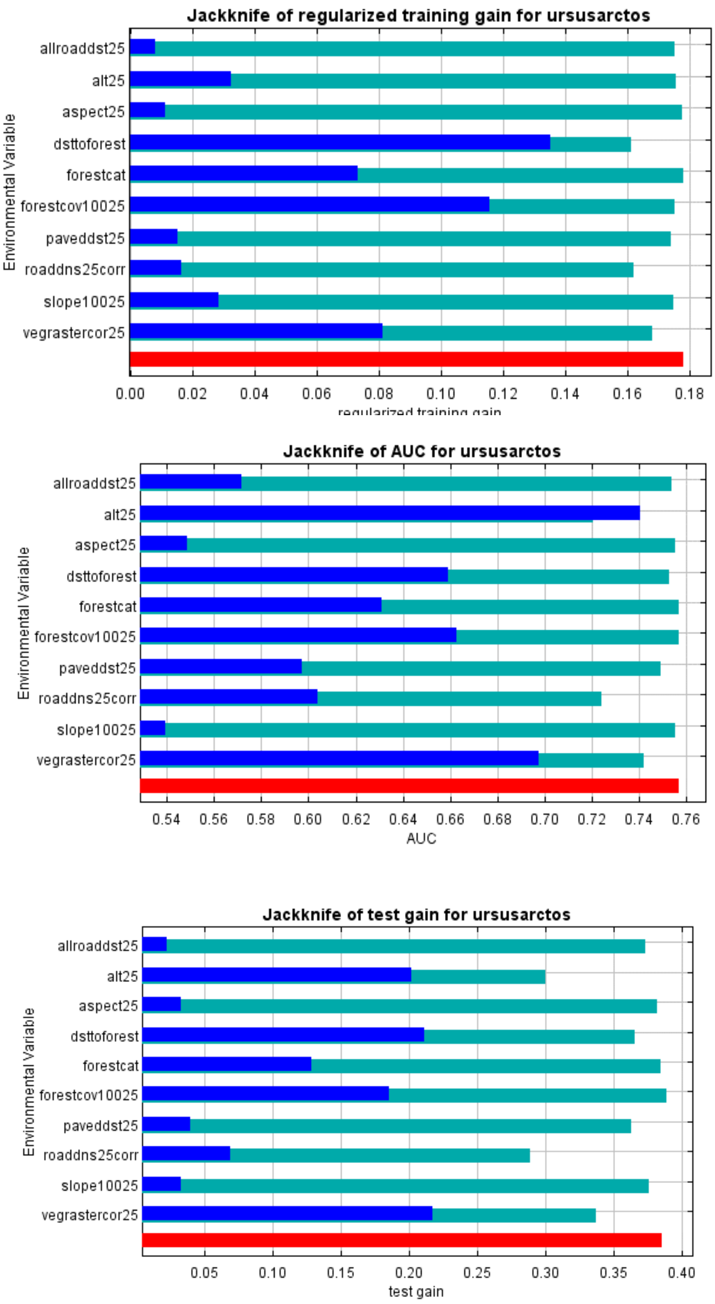


Figure 20. Omission-commission graph of the selected average model

The omission-commission graph shows that there is probably an issue with spatial autocorrelation of the data which is expected as GPS telemetry locations were used (very dense spatiotemporal segregation). Although there was a considerable thinning and filtering of the data it was not possible to eliminate completely the spatial autocorrelation, and thus an advanced bootstrapping of the data with multiple runs of the MAXENT with independent subsets of GPS locations could probably further reduced the problem[19].



allroadsdst **:** Distance from rod network (all types)
Alt25= Altitude at each grid cell,
Aspect25= aspect at each grid cell,
Dstforest: Distance from nearest forest patch
Forestcat: NO forest, Deciduous, Conifers
ForestCov100: Forest cover at 100m radius
Paveddst= Distance from paved roads,
Roaddns= Density of roads (including forest roads),
Slope 100= Average slope at 100m radius from each grid cell,
Vegrastercor= Vegetation categories form forest maps

Without variable
With only variable
With all variables

Figures 21. Jackknife on training data gain and test data AUC. The environmental variables with the highest gains when used in isolation both for the training set and AUC gain, were: Distance from forest, Forest cover, Vegetation class, Altitude and main forest type. Other important variables included road density and distance from paved roads.

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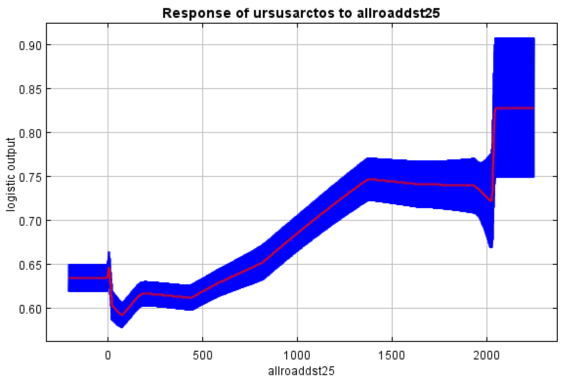
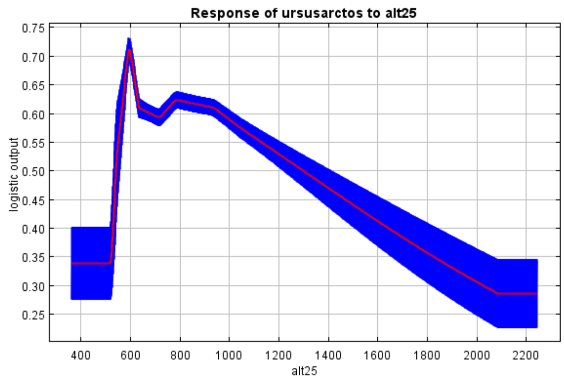
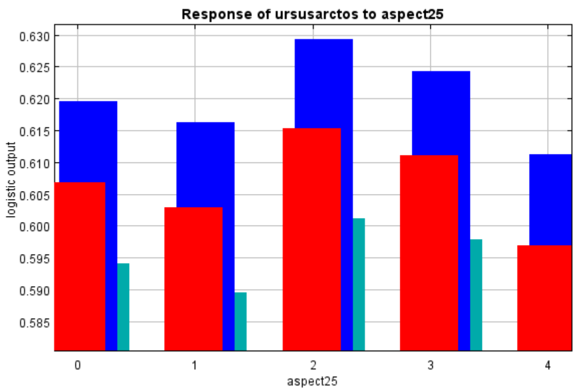
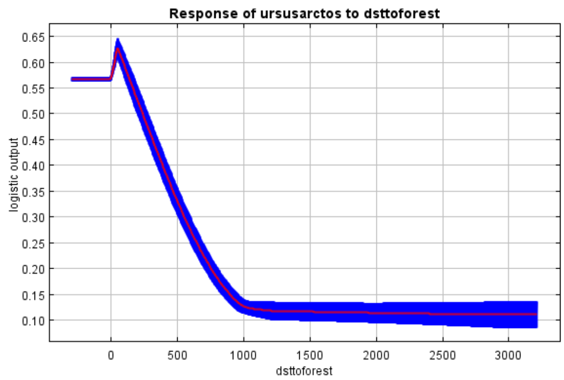
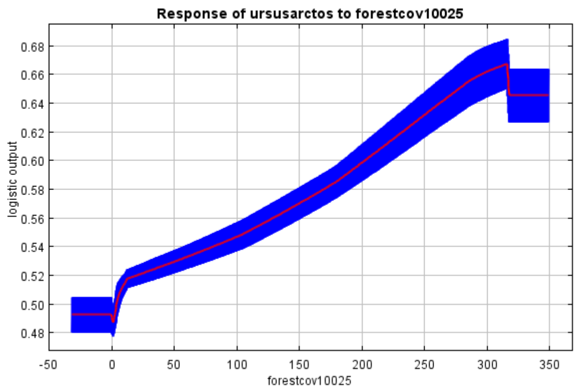
[19] Edrén, S.M.C., Wisz, M.S., Teilmann, J., Dietz, R. and Söderkvist, J. (2010), Modelling spatial patterns in harbour porpoise satellite telemetry data using maximum entropy. Ecography, 33: 698-708. https://doi.org/10.1111/j.1600-0587.2009.05901.x

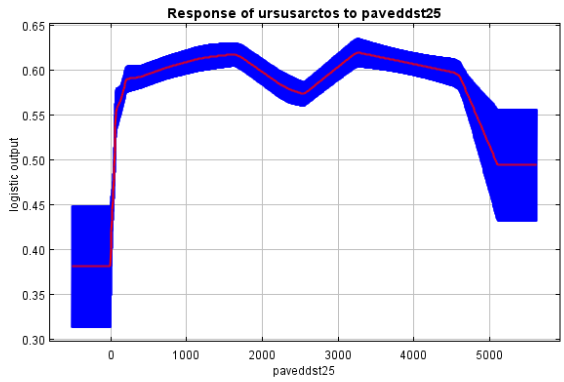

Response of ursusarctos to allroaddst25
logistic output
allroaddst25

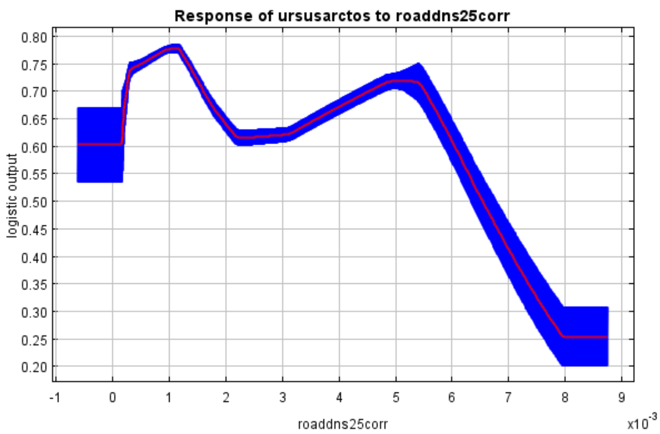

Response of ursusarctos to alt25
logistic output
alt25

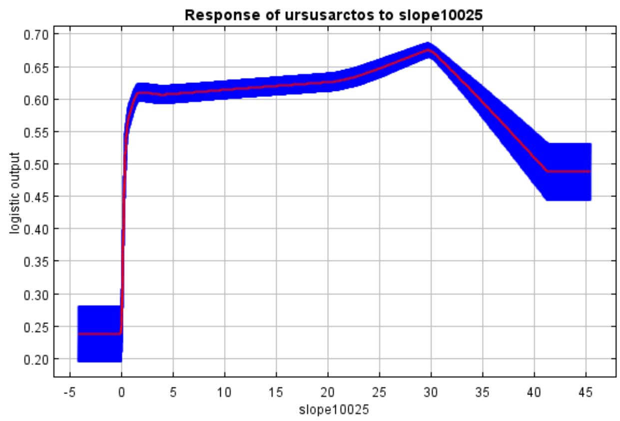

Response of ursusarctos to aspect25
logistic output
aspect25

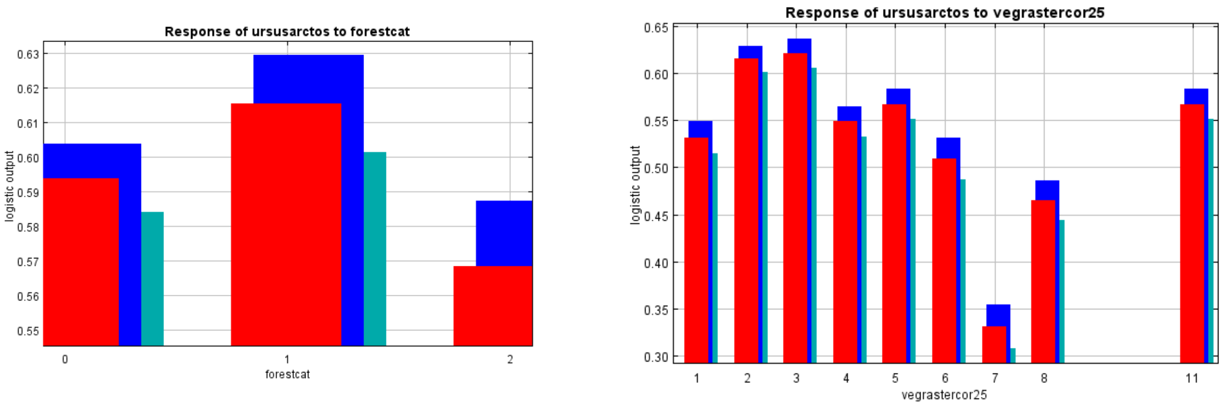

Response of ursusarctos to dsttoforest
logistic output
dsttoforest


Response of ursusarctos to forestcov10025
logistic output
forestcov10025


Response of ursusarctos to paveddst25
logistic output
paveddst25


Response of ursusarctos to roaddns25corr
logistic output
roaddns25corr
x10-3


Response of ursusarctos to slope10025
logistic output
slope10025



Figures 22. Response curves for each variable related to bear habitat suitability. These curves show how each environmental variable affects the Maxent prediction and how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.
Values for aspect class: 0=flat, 1=north, 2=east, 3=south, 4=west.
Values for main forest classes are: 0= No forest, 1 = Deciduous forests 2= Conifer

Bear habitat suitability as studied with telemetry increased with **altitude** until approximately 800m., and then decreased with further altitude increment at least for the season studied. Although bears use forest roads for moving in the study area, suitability of bear habitat increased as distance from any **road class or road density** increased. Habitat suitability also increased with **increments of forest cover** and decreased when distance from forest edge increased. Additionally, there was a preference for the **medium slope classes** (flat and steep areas were less preferred). Bear preferred mostly **oak forests and mixed agricultural** habitats. In conclusion forest cover and human infrastructure shaped movement and habitat use of collared bears during the studied period.

9.6 Bear habitat suitability maps

A bear habitat suitability map was created at the logarithmic scale and normalized scale (Raw format). When in logarithmic scale suitability is ranked from 0 to 1 per each grid cell, while in raw format the sum of **all suitability values** calculated for all background grid cells are equaling 1. As Maxent's logistic output relies on an assumption, not an estimation, of prevalence (default =0,5) , thus the logistic maps should be used cautionary.

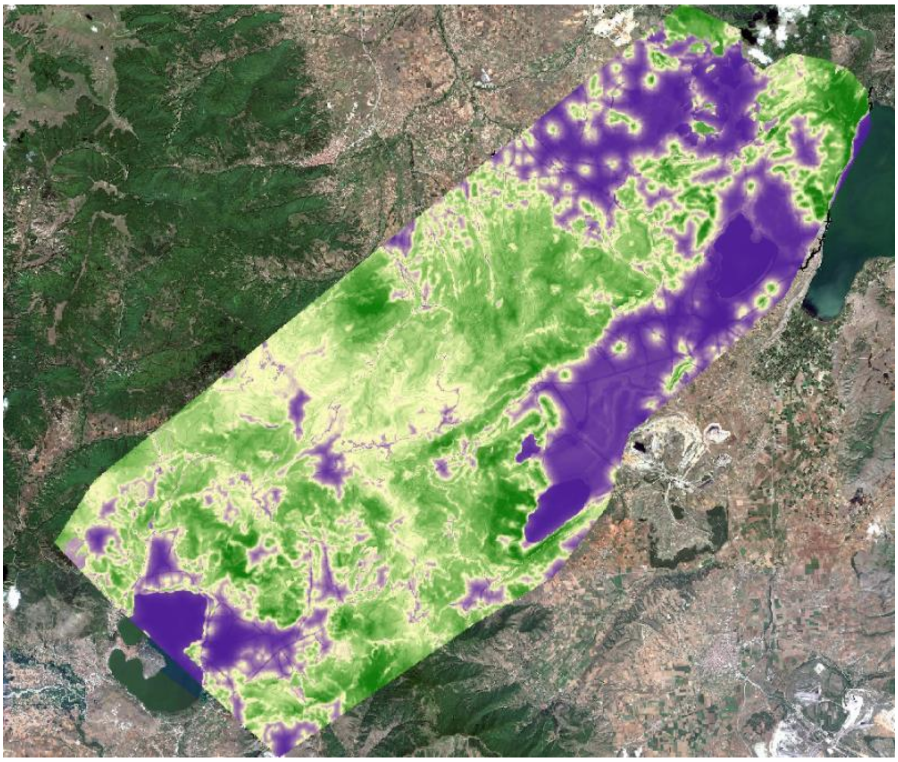


Figure 23. Bear habitat suitability map of the study area after analysis of bear telemetry data with MAXENT at logarithmic output (CLog-log). Highly suitable areas are shown with green, and those with lowest suitability with purple.

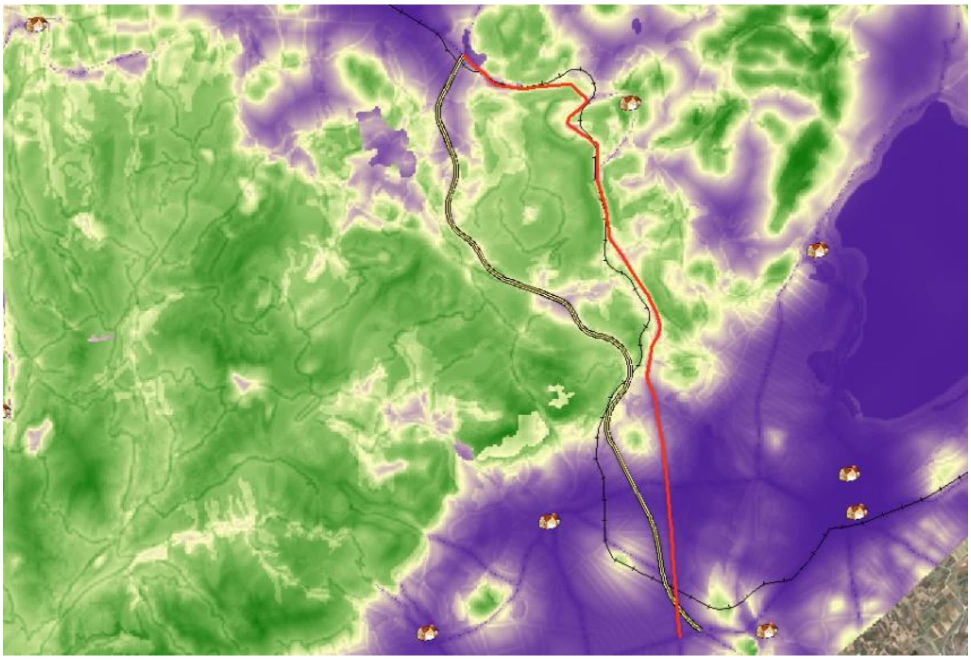


Figure 24. Detail from the bear habitat suitability map along the New and Old highway from Amyndaio to Vevi where most of the bear accidents have been reported. Note the drop of suitability along paved roads

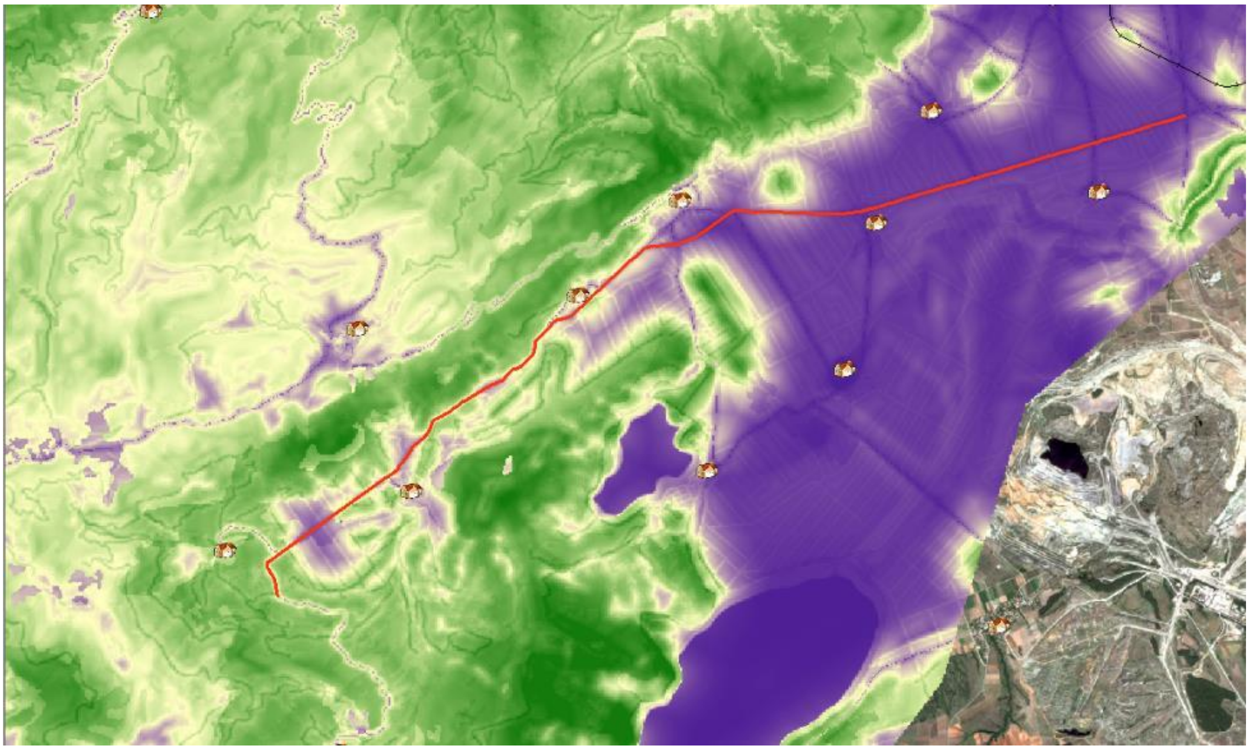


Figure 25. Detail from the bear habitat suitability map along the Xino Nero-Sklitho road segment

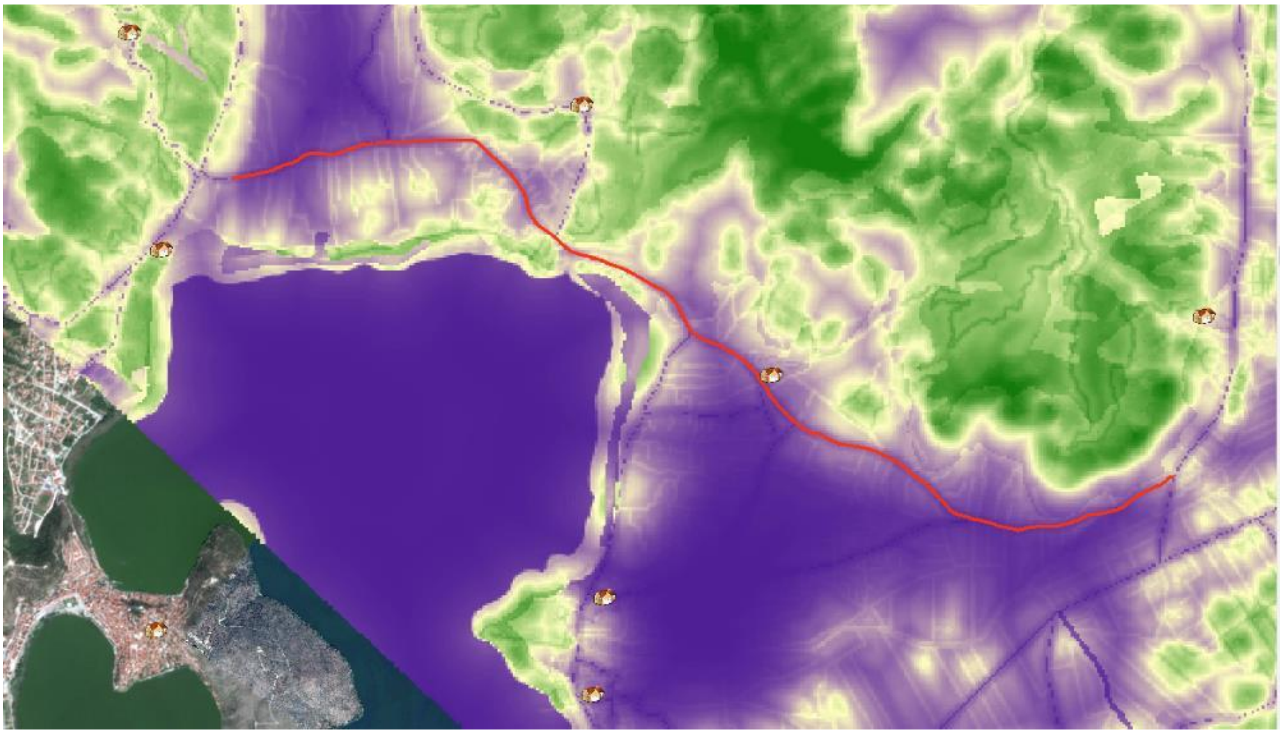


Figure 26. Detail from the bear habitat suitability map along the Foteino- Metamorphosi road segment.

10. Linkage corridor analysis to define crossing probabilities per segment.

The next step was to use the habitat suitability map produced with MAXENT to model and create an approximation of bear crossings by predicting which would be the most appropriate corridors in the landscape. The bear habitat suitability map was converted to a landscape bear **resistance map** by assigning the most suitable cells with a value of 1 (lowest resistance) and the less suitable areas with a value of 10 (Natural Jenks reverse classification). Lakes were assigned as 'no data' areas, as not to interfere with the corridor analysis.

Apart from the resistance map, linkage analysis also needs a network of protected areas to connect. Rather than select or create arbitrarily a network of supposedly important areas for bears or select from an already existing network of protected areas (like for example the hunting reserves or Natura 2K areas) we instead created that network from the suitability maps assuming that bears in the study area will move in between a network of the most suitable areas.

We selected the upper 10th class from the bear suitability raster map (Natural Jens classification) and created a feature shape file. From this shapefile we then selected the **upper 10TH quantile** class according to their shape area size (i.e. selection for the largest of the most suitable areas for bears). To reduce computational time and excess complexity of the connectivity maps we reduced the number of polygons by rejecting smaller ones in high suitability polygon clusters, when their distance was less than 1000m from the largest neighboring polygon of each cluster. The final network consisted of **51 polygons** (i.e. the "core area network").

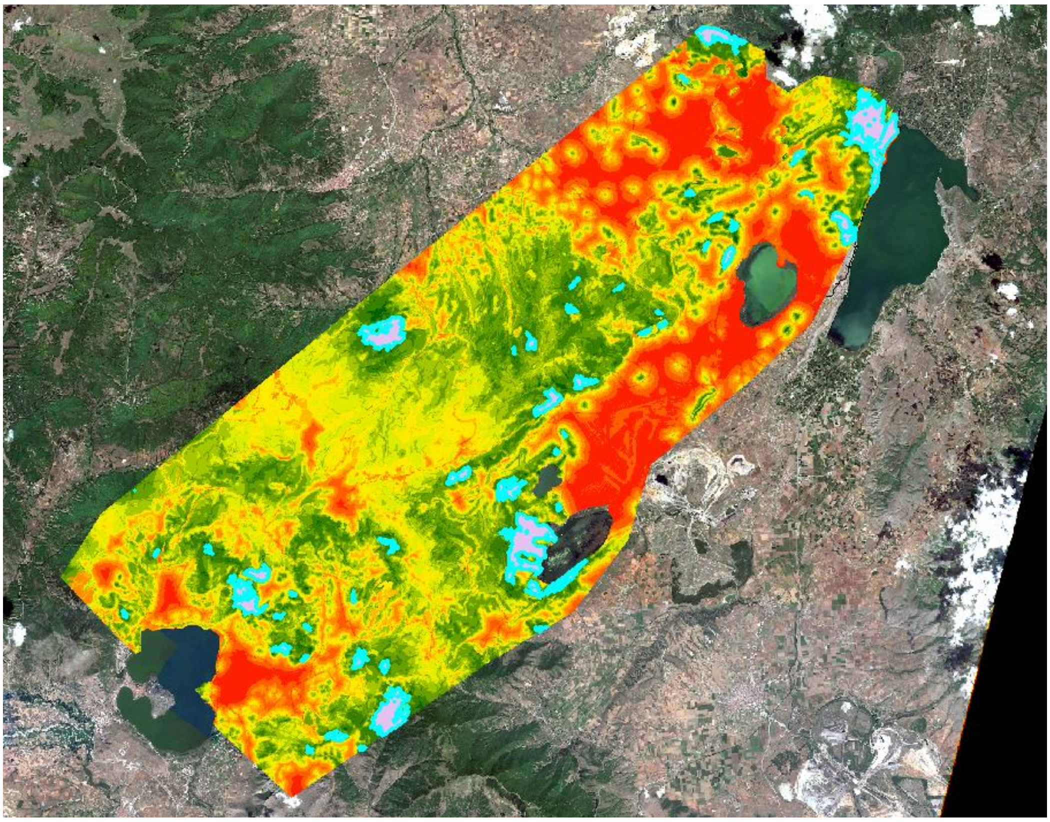


Figure 27. "Resistance map" used for corridor analysis, with red areas having the highest resistance for bear movement and the greener areas the lowest. Highlighted areas in light blue are those in the highest suitability class (Upper 10th Natural Jenks class) and the largest in size (Upper 10th Quantile class) i.e. the core area network.

Linkage analysis was undertaken with the Linkage Mapper[20] ArcGIS toolbox. The output of the software is a raster resistance map (25X25m) showing the most probable corridors that connect patches with highly suitable bear habitat.

[20] Gallo, J. A., & R. Greene. 2018. Connectivity Analysis Software for Estimating Linkage Priority. Conservation Biology Institute, https://doi.org/10.6084/m9.figshare.5673715

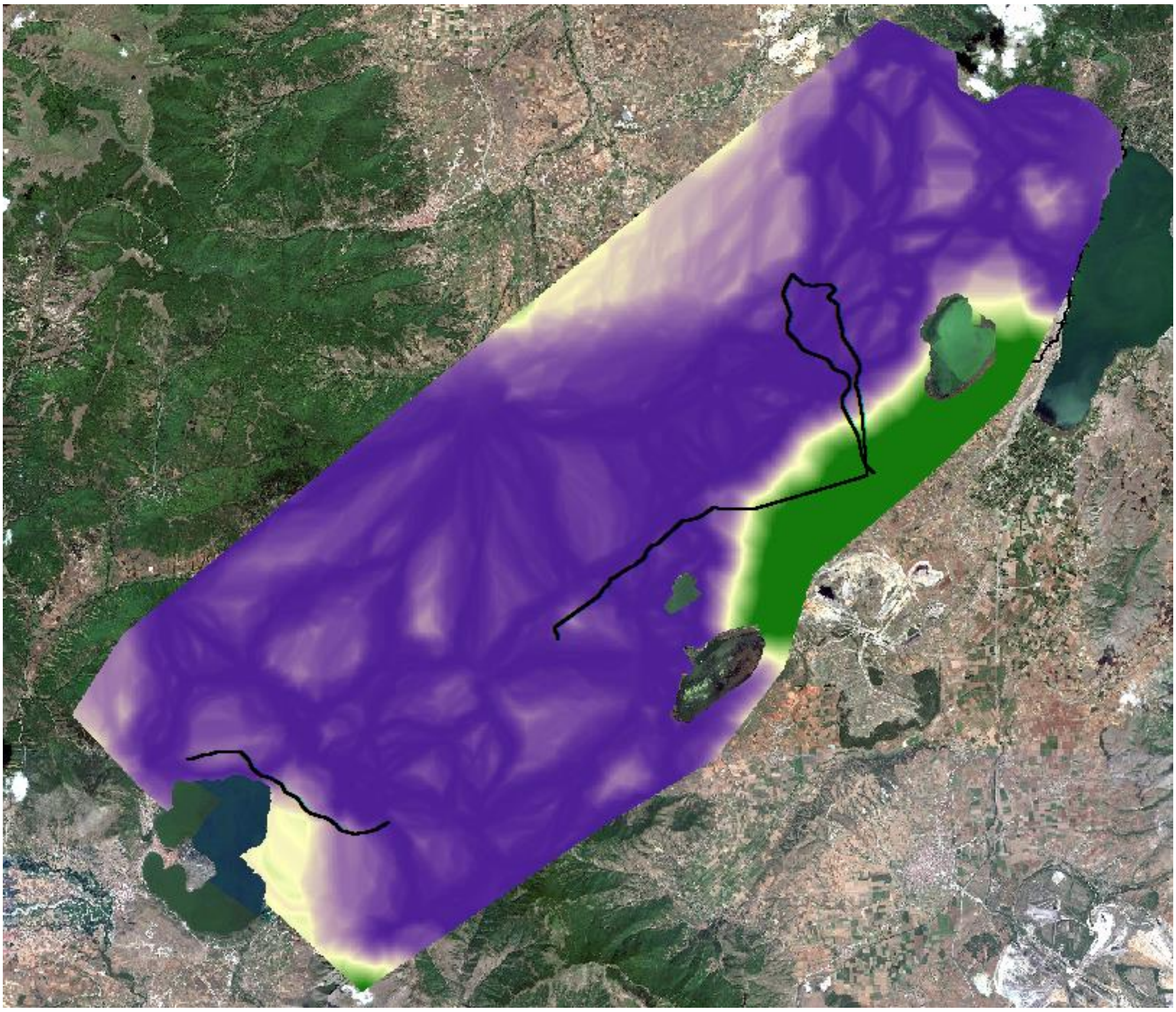


Figure 28. Map showing a bear connectivity map based on telemetry data (habitat suitability analysis). Deep purple areas are those with low resistance score (i.e., more suitable for movement. Prior risk collision analysis, the raster map was **rescaled with a reverse logarithmic function** (i.e. most suitable for connectivity area to reach a value of 1).

10.1Connectivity predictions per point and road segment

To permit further analysis of the results, values from the connectivity map (reversed recalled with logarithmic function) were assign to each point of the road segments. Visualization of the connectivity relative suitability for each point/road segment is present in the following maps.

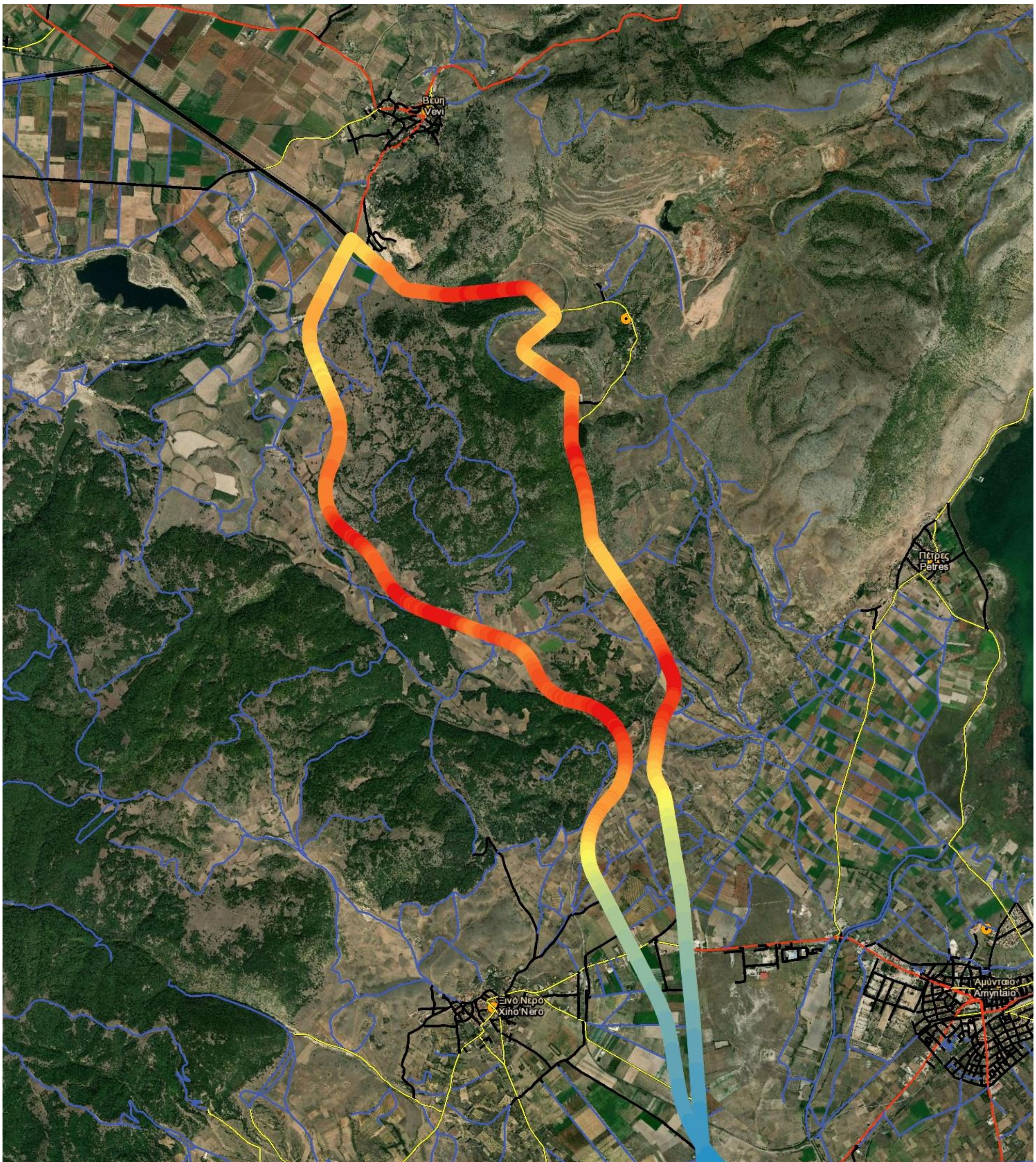
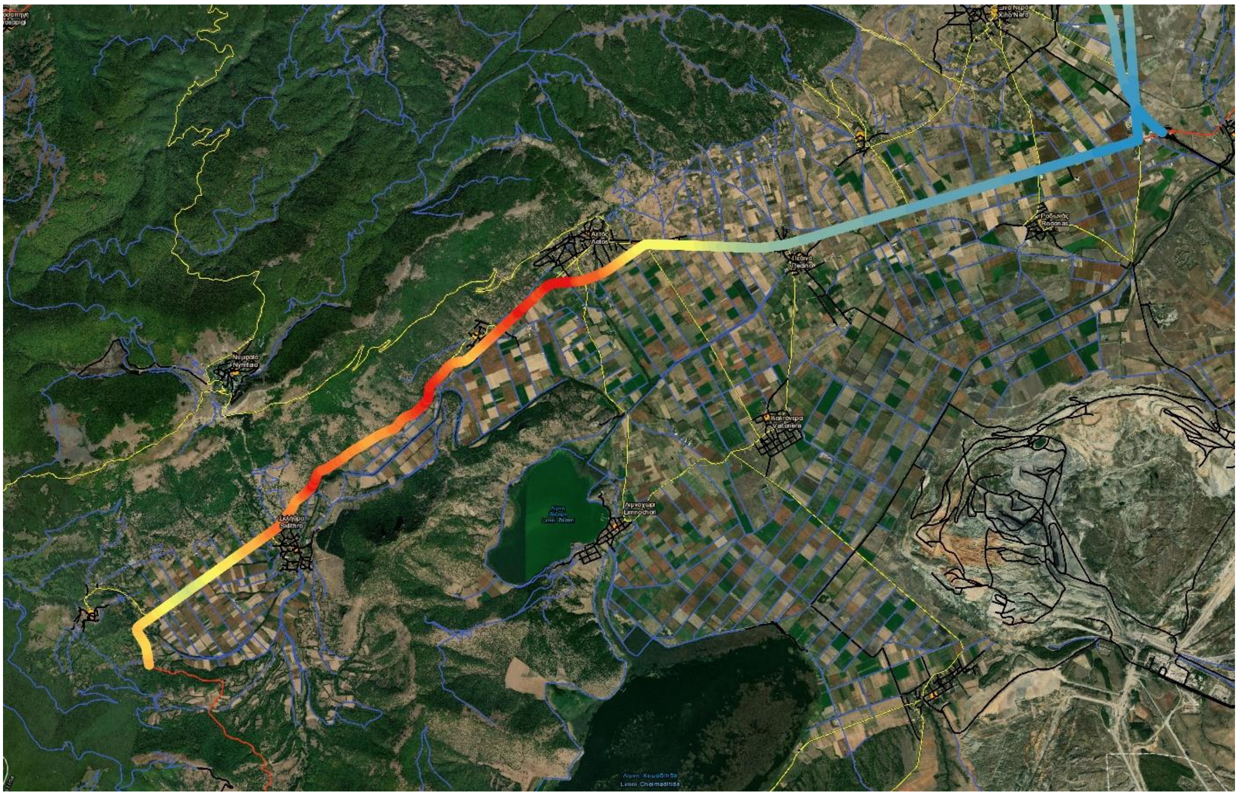
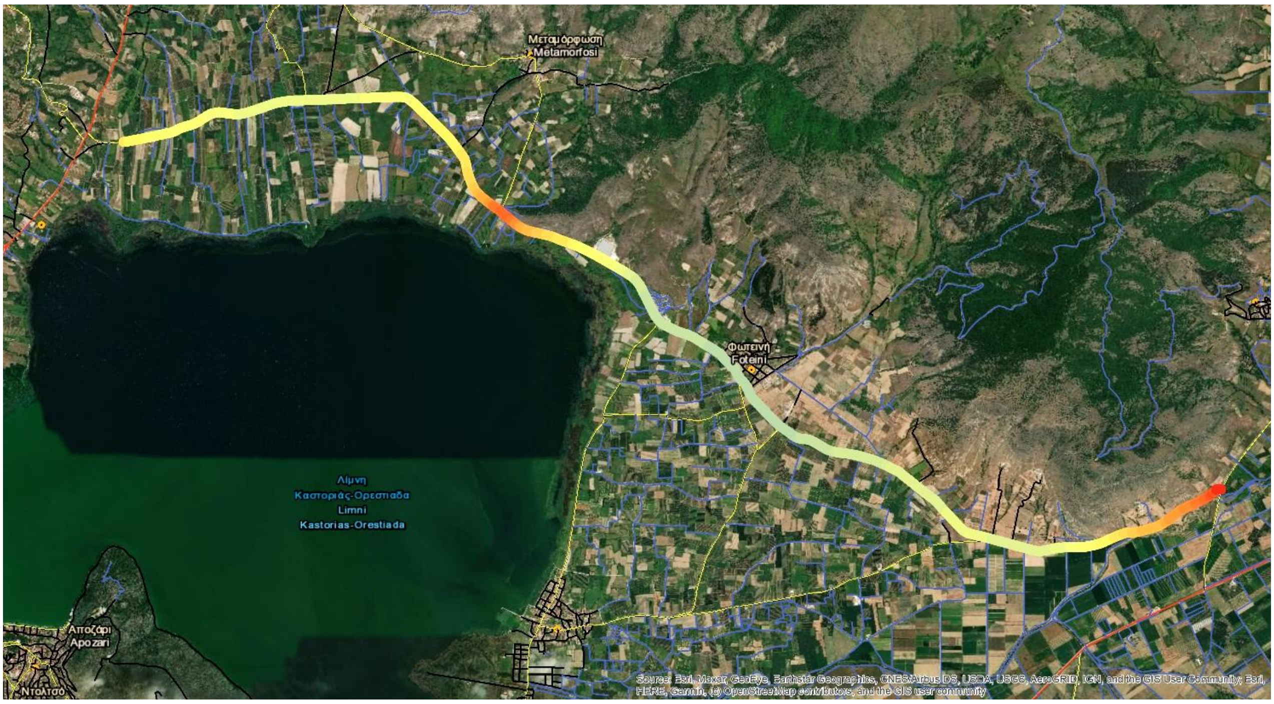


Figure 29. Connectivity suitability at the logarithmic scale derived from telemetry locations after Maxent modeling and subsequent connectivity analysis, in the **New and old highway from Amydaio to Vevi.** Warmer colors indicate higher suitability for crossing.





Figures 30. Connectivity suitability in the **road segment from Xino Nero to Aetos** (upper map) and **Foteini- Metamorhosi** segments. Warmer colors indicate higher suitability for crossing .

11.Analysis of bear road-crossing data from ground surveys

11.1Creation of bias file for analysis of crossing data with MAXENT

Monitoring of road segments was not uniform for every part of the roads examined. As all tracks have been mapped in the field using a GPS device it was possible to calculate for each road segment point the **exact number of visitations during the study (n= 0-10).** An attribute field ("Repetition") was assigned to each point (10m interval) and a value was given equal to the number of visitations per point. A Kernel density raster layer (resolution 10m) was created with a search radius of 50meters and then clipped with a buffer feature of a radius of 20m around road segment points to represent a bias file for MAXENT runs.

Figure 31. Sampling routes along the new "Amydaio- Florina" highway. Seasonal sampling routes are represented with different color.

Figure 32. Sampling bias file created with Kernel density analysis based on sampling repetition value per road point. The bias file covers only the area around the roads at a buffer distance of 20 m. Bias file creation is a crucial step for MAXENT analysis. Numbers indicate sampling repetition frequencies per segment point.

11.2 MAXENT Runs for brown bear crossing data- Parametrization and results

Maxent run for crossing data was undertaken only over road points (10m interval). All bear crossing points were assigned spatially (slightly moved at a 90 degree from their original mapped position) and over the center of each road segment. Thus, MAXENT evaluated all relevant parameters (predictors of crossing points) using their values that corresponded exactly to the **centerline of the road segments** in concern. Spatial resolution was kept at 10m (equal to available grid cell size) to achieve the most spatial accuracy possible.

As with the bear telemetry analysis, a correlation matrix was created to avoid the simultaneous inclusion in the models of predictors with more than a Pearson R value of 0.65.

	altcrs	embdnscrs	farmdnscrs	farmdstcrs	forrdstcrs	guarddnscrs	nvdi100crs	nvdi500crs	nvdi1000crs	orygdnscrs	roadalldnscrs	slope100crs	slope500crs	slopecrs	traindstcrs	trbarcrs	undpassdstcrs	verg10crs	verg20	villagdstcrs	walfdnscrs	walldstcrs
altcrs	1,00	0,34	0,04	0,04	0,24	0,40	0,48	0,20	0,41	0,36	-0,79	0,36	0,98	0,32	-0,06	-0,17	-0,01	-0,04	0,08	0,41	0,06	-0,58
embdnscrs	0,34	1,00	-0,03	-0,03	0,02	0,87	0,08	-0,06	0,01	0,02	-0,18	0,15	0,32	0,13	-0,31	-0,35	-0,33	-0,04	0,13	0,38	-0,12	-0,09
farmdnscrs	0,04	-0,03	1,00	1,00	0,08	-0,08	0,03	0,00	-0,09	0,02	0,20	-0,03	0,04	-0,04	-0,25	-0,21	0,48	-0,13	-0,23	-0,29	-0,20	0,06
farmdstcrs	0,04	-0,03	1,00	1,00	0,08	-0,08	0,03	0,00	-0,09	0,02	0,20	-0,03	0,04	-0,04	-0,25	-0,21	0,48	-0,13	-0,23	-0,29	-0,20	0,06
forrdstcrs	0,24	0,02	0,08	0,08	1,00	-0,05	0,14	0,09	0,15	0,12	-0,24	0,47	0,32	0,49	-0,25	-0,27	0,00	0,05	0,03	-0,05	-0,10	0,08
guarddnscrs	0,40	0,87	-0,08	-0,08	-0,05	1,00	0,08	-0,11	0,01	0,02	-0,18	0,03	0,36	0,02	-0,32	-0,37	-0,38	-0,15	0,05	0,50	-0,09	-0,10
nvdi100crs	0,48	0,08	0,03	0,03	0,14	0,08	1,00	0,69	0,90	0,25	-0,58	0,31	0,53	0,28	0,04	-0,01	0,10	0,00	0,13	-0,03	-0,10	-0,50
nvdi500crs	0,20	-0,06	0,00	0,00	0,09	-0,11	0,69	1,00	0,80	0,04	-0,37	0,19	0,25	0,17	0,20	0,18	0,20	0,26	0,33	-0,21	-0,07	-0,35
nvdi1000crs	0,41	0,01	-0,09	-0,09	0,15	0,01	0,90	0,80	1,00	0,16	-0,54	0,28	0,46	0,26	0,18	0,13	0,12	0,14	0,26	-0,06	-0,03	-0,49
orygdnscrs	0,36	0,02	0,02	0,02	0,12	0,02	0,25	0,04	0,16	1,00	-0,35	0,28	0,38	0,22	-0,15	-0,19	-0,10	0,04	0,12	0,23	0,02	-0,26
roadalldnscrs	-0,79	-0,18	0,20	0,20	-0,24	-0,18	-0,58	-0,37	-0,54	-0,35	1,00	-0,49	-0,82	-0,44	-0,05	0,04	0,09	0,02	-0,09	-0,11	-0,15	0,62
slope100crs	0,36	0,15	-0,03	-0,03	0,47	0,03	0,31	0,19	0,28	0,28	-0,49	1,00	0,52	0,95	-0,29	-0,35	-0,06	0,18	0,22	0,15	-0,07	-0,16
slope500crs	0,98	0,32	0,04	0,04	0,32	0,36	0,53	0,25	0,46	0,38	-0,82	0,52	1,00	0,47	-0,09	-0,19	0,00	-0,02	0,11	0,37	0,04	-0,58
slopecrs	0,32	0,13	-0,04	-0,04	0,49	0,02	0,28	0,17	0,26	0,22	-0,44	0,95	0,47	1,00	-0,26	-0,32	-0,06	0,17	0,21	0,11	-0,07	-0,13
traindstcrs	-0,06	-0,31	-0,25	-0,25	-0,25	-0,32	0,04	0,20	0,18	-0,15	-0,05	-0,29	-0,09	-0,26	1,00	0,99	0,50	0,15	0,11	-0,26	0,35	-0,57
trbarcrs	-0,17	-0,35	-0,21	-0,21	-0,27	-0,37	-0,01	0,18	0,13	-0,19	0,04	-0,35	-0,19	-0,32	0,99	1,00	0,52	0,15	0,10	-0,32	0,33	-0,49
undpassdstcrs	-0,01	-0,33	0,48	0,48	0,00	-0,38	0,10	0,20	0,12	-0,10	0,09	-0,06	0,00	-0,06	0,50	0,52	1,00	0,08	0,00	-0,35	0,04	-0,16
verg10crs	-0,04	-0,04	-0,13	-0,13	0,05	-0,15	0,00	0,26	0,14	0,04	0,02	0,18	-0,02	0,17	0,15	0,15	0,08	1,00	0,84	-0,01	0,04	-0,04
verg20	0,08	0,13	-0,23	-0,23	0,03	0,05	0,13	0,33	0,26	0,12	-0,09	0,22	0,11	0,21	0,11	0,10	0,00	0,84	1,00	0,15	0,03	-0,12
villagdstcrs	0,41	0,38	-0,29	-0,29	-0,05	0,50	-0,03	-0,21	-0,06	0,23	-0,11	0,15	0,37	0,11	-0,26	-0,32	-0,35	-0,01	0,15	1,00	-0,03	-0,07
walfdnscrs	0,06	-0,12	-0,20	-0,20	-0,10	-0,09	-0,10	-0,07	-0,03	0,02	-0,15	-0,07	0,04	-0,07	0,35	0,33	0,04	0,04	0,03	-0,03	1,00	-0,28
walldstcrs	-0,58	-0,09	0,06	0,06	0,08	-0,10	-0,50	-0,35	-0,49	-0,26	0,62	-0,16	-0,58	-0,13	-0,57	-0,49	-0,16	-0,04	-0,12	-0,07	-0,28	1,00

Table xx, Correlation matrix for predictors used in MAXENT 3.4.1 for analyzing bear crossing locations

Maximum number of **permitted iterations** was set to 5000. **Regularization multiplier** was set to 1,5 slightly increased from the default option to allow for a better dispersion of predictions. Larger values of the regularization b- multiplier were not tested as the goal of this analysis was to provide spatially accurate crossing hot spots. **Prevalence** was set to default value, τ= 0.5 as the species is a generalist and common in the study area[21] .

A bias file (kernel raster) that corresponded to the exact sampling effort per point and road segment was used (see related paragraph). The default option (auto) was set for feature selection (linear, quadratic, product and hinge selected). Duplicate crossings inside the same grid cell would be omitted from analysis to reduce spatial autocorrelation and over representation of the model prediction in multiply crossed cells. Thus, there was a decrease of the crossing sample size from 176 to 143 crossing points.

Maxent was run in a set of preliminary models using as validation method the "random test percentage" option (with one replication per run) to permit several repetitions with many combinations (i.e. >60) of variables in a reasonably achieved analysis time. 25% of the provided crossings were used each time as test set.First, the Maxent algorithm was run a series univariate models for each one of all predictor variables. The best (highest AUC value) univariate (single variable) model was set as the baseline model. A stepwise forward procedure was used to build the models. We excluded from next runs variables that could reduce the overall test gain and the overall test AUC value, compromising the predictive value of the model.

From the initial set of 29 predictors tested, only 9 were included in the final candidate models. The procedure described provided **5 final candidate models**. To select the most suitable model we used an independent analysis (ENM Tools) especially designed to select the best model amongst several candidate output models from the MAXENT using information criteria.

11.3 Final crossing model selection

We used ENM Tools v.13[22] which is an especially designed algorithm to analyze maxent outputs and was used to select amongst the five candidate models. This function allows criterion-based model selection using AIC, AICc, and BIC (Warren and Seifert 2011[23], Burnham and Anderson 2002[24]). When this function is selected, ENMTools asks for a script file

[21] Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. and Yates, C.J. (2011), A statistical explanation of MaxEnt for ecologists. Diversity and Distributions, 17: 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

[22] Warren, D.L., R. E. Glor, and M. Turelli. 2008. Environmental niche equivalency versus conservatism: quantitative approaches to niche evolution. Evolution 62:2868-2883

[23] Warren, D.L., and S.N. Seifert.. Environmental niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications. (doi: 10.1890/10-1171.1)

[24] Burnham, K. P., and D. R. Anderson, 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag. ISBN 0-387-95364-7.

containing ASCII raster files and lambdas files, provided by MAXENT outputs, for the models being compared, along with .csv files of occurrences. Results of the procedure are shown in the following table. Warren and Seifert propose AICc as the most suitable diagnostic for best model performance especially for small sample sizes like in our case.

Table 13, Variables used in the final candidate models

	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5
ALLBARDNS (Density of supporting wall, fences and other barriers)	X	X	X	X	X
ALLBARDST (Distance from supporting wall, fences and other barriers)			X		X
EMBDNS (Density of road embankments)	X			X	X
FARMDNS (Density of Farms)	X	X			
FARMDST (Distance from Farms)	X				
FORCOV1000M (Forest cover at a radius of 1000m)	X	X	X	X	X
VERGE20 (Density of vegetation around the road verges up to 20m from road edges)	X	X	X	X	X
VILLAGEDST (Distance from Villages)	X	X	X	X	X
WATER (Distance from permanent water)	X	X	X	X	X
Test set AUC values	**0.833**	**0.881**	**0.886**	**0.887**	**0.881**

Table 14. ENM Tools diagnostics for the top candidate models

Model Name	Log Likelihood	Parameters	Sample Size	AIC score	AICc score	BIC score
MODEL1	-124.820	62	143	262.040	271.805	280.409
MODEL2	-126.527	43	143	261.655	265.478	274.396
MODEL3	-126.037	56	143	263.275	270.698	279.867
MODEL4	-124.890	46	143	**258.981**	**263.485**	**272.610**
MODEL5	-126.570	52	143	263.540	269.665	278.947

According to ENM Tools output, appears that the "best" model is MODEL 4 as it combines lowest values for all information criteria calculated (AIC, AICc, BIC)

11.4 Final MAXENT model for the distribution of bear crossing points.

For the final model selected the maxent algorithm was let to rerun the analysis for 30 replications with a random selection of test locations at each run (k=29). Evaluation of the models was undertaken with k- fold cross validation with the random seed selection enables (i.e. different combinations of training and test set for each run) and removal of duplicate presence points in cells. The final model -as the preliminary ones -was run under a 1,5-regularization b-multiplier.

The model included 6 out of the 29 environmental variables initially tested. The average test AUC for the replicate runs is **0.868**, and the standard deviation is **0. 079.**

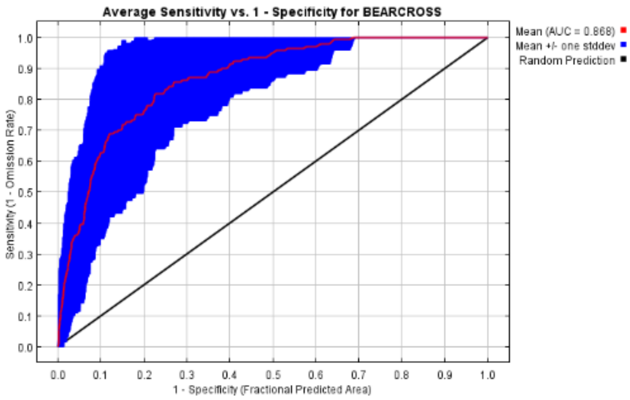


Figure 33. Average AUC value of the selected model after 30 replications.

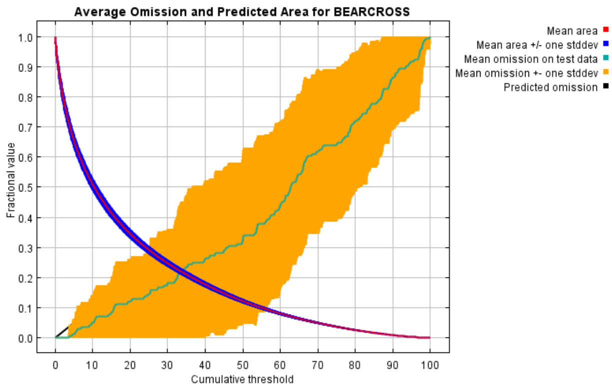
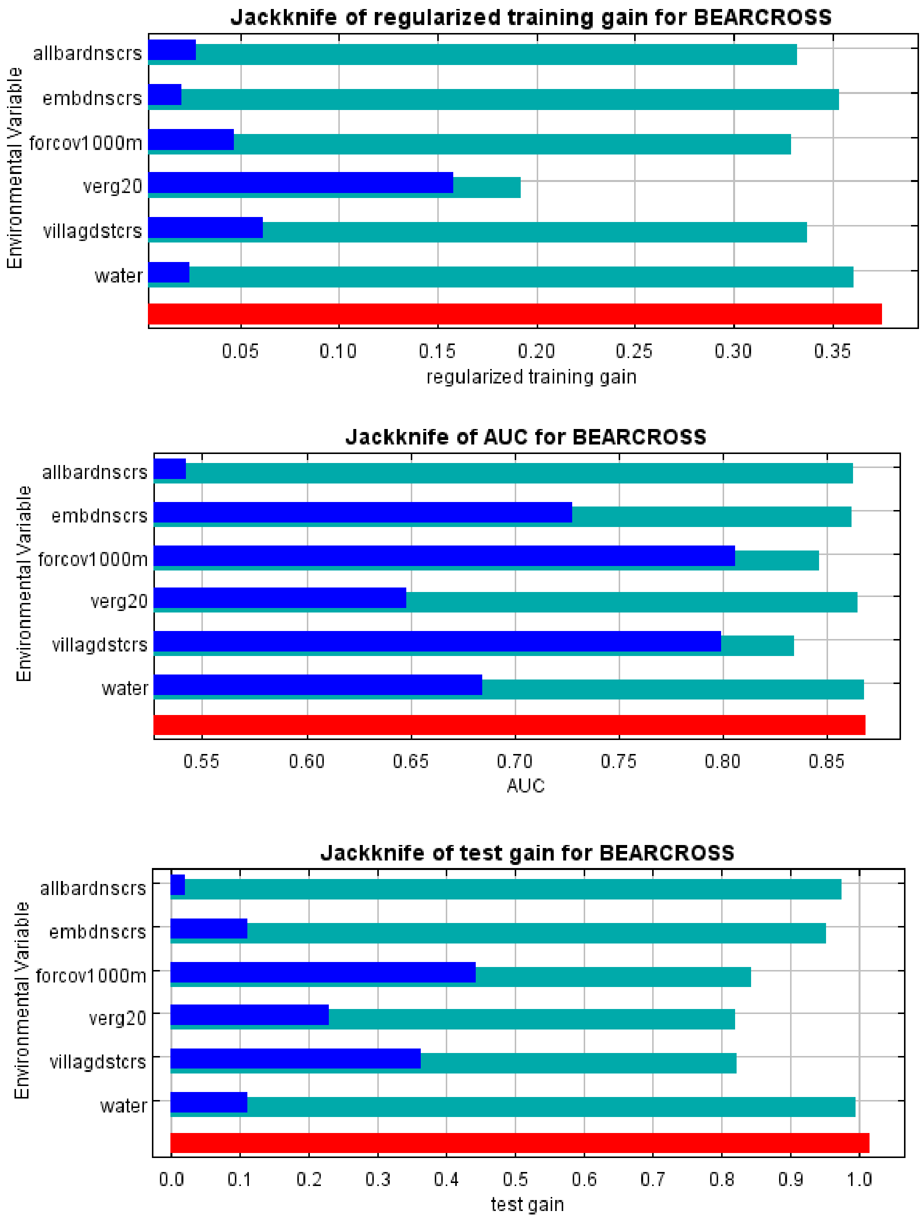


Figure 34. Omission-commission graph of the selected average model



Allbardns= Density of supporting walls and fences at road verges

Embdns = Density of road embankments

Forcov1000m = Forest cover (sum) at a radius of 1000

Verg20= Density of vegetation verges up to 20m from road centerline

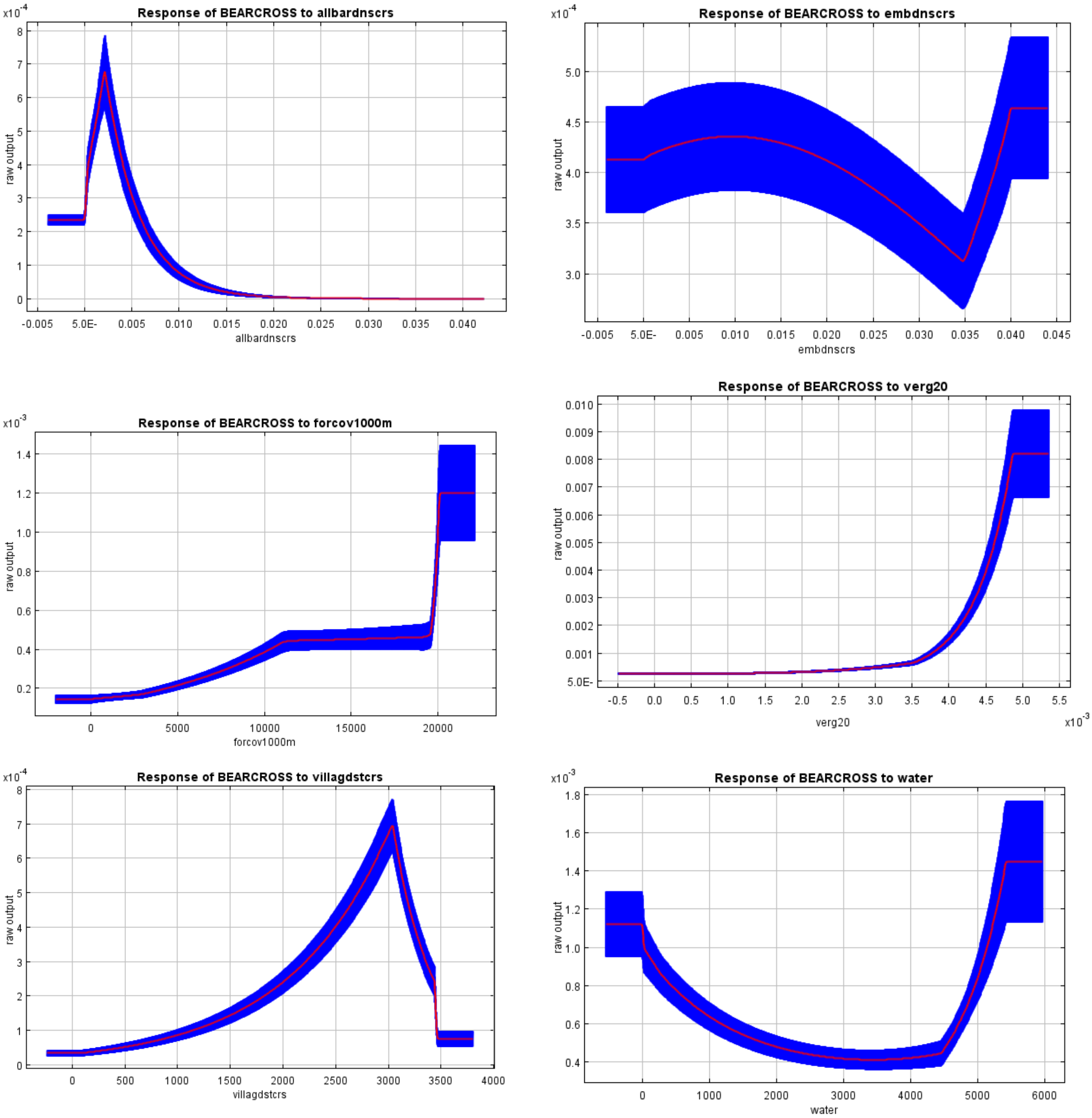
Villagdst= Distance form villages

Water= Distance form water

Figures 35. Jackknife on regularized training data gain, test data gain and test AUC.

The environmental variables with the highest gains when used in isolation in the training set and AUC gain, were:

- **Forcov1000m** = Forest cover (sum) at a radius of 1000,
- **Villagdst**= Distance form villages,
- **Verg20**= Density of vegetation verges up to 20m from road centerline,
- **Water**= Distance form water
- **Embdns** = Density of road embankments,
- **Allbardns**= Density of supporting walls and fences at road verges,



Figures 36. Response curves of each variable related to bear crossing suitability when maintaining the rest of the variables in their mean value.

Several factors affected the **distribution on bear road-crossings** in the road segments under evaluation. Amongst landscape factors forest cover at the 1000m scale, distance from villages and presence of permanent water was the most important variables of those tested. Bears mostly crossed roads and highways in areas that **neighbored more forested areas**, at some distance from villages and closer to water. Bears preferred crossing roads at a range approximately between **2000-3500 meters from villages** while crossing probabilities were lower when closer or further out of this range (polynomial response curve).

Apart from those landscape features, road characteristics greatly affected crossing probabilities. Bears seem to prefer crossing sites related to embankments, although this result could additionally be linked to detection probabilities during field work (detection of crossing tracks over guardrails).

Presence of vegetation at road verges and up to 20 meters from the road edges had a critical role on defining crossing sites at a finer spatial scale, with bears selecting road points closer to small forest and scrub patches adjacent to roads. This behavior may significantly increase the risk of collision with passing vehicles as visibility at these points is extremely limited for both animals entering the road deck and passing drivers who fail to spot timely approaching wildlife. Even in parts of the road where visibility to road surface is theoretically good for an approaching bear (e.g. in straight or open turns entering from the outer curve), the presence of vegetation near road verges significantly limits visibility.

Where **large supporting walls** (to prevent land sliding) or other **barriers were adjacent to roads** and also combined with suitable areas for crossing (e.g. forested verges) tend to **concentrate and funnel animal movements over roads to their edges** creating hot spot crossing points. The relative figure (i.e. variable allbardns) shows that crossings are minimal at high barrier densities but rapidly increase at low barrier densities (I.e. edge effect and funneling).

Figures 37 Supporting road walls act as barriers to wildlife movements but when combined with good crossing habitat funnel animals at their edges to create hot spot crossing points (Aetos-Sklethro road segment). Note the bear /wildlife path at the left picture.

Figure 38.
Bear crossing over guard rails on the new Amyntaio-Vevi highway at a point with limited visibility due to seasonal vegetation of blackberries, reeds and scrubs near road edges.

11.5 Crossing-suitability predictions per point and road segment based on ground surveys.

Values from the crossing suitability analysis (distribution of crosses) derived from raster Maxent outputs were assign to each point of the road segments under evaluation. Visualization of the relative crossing suitability for each point/road segment is presented in the following maps. Values are in the logarithmic format to permit conceptualization and direct comparison with the respective analysis and map form the telemetry-connectivity model.

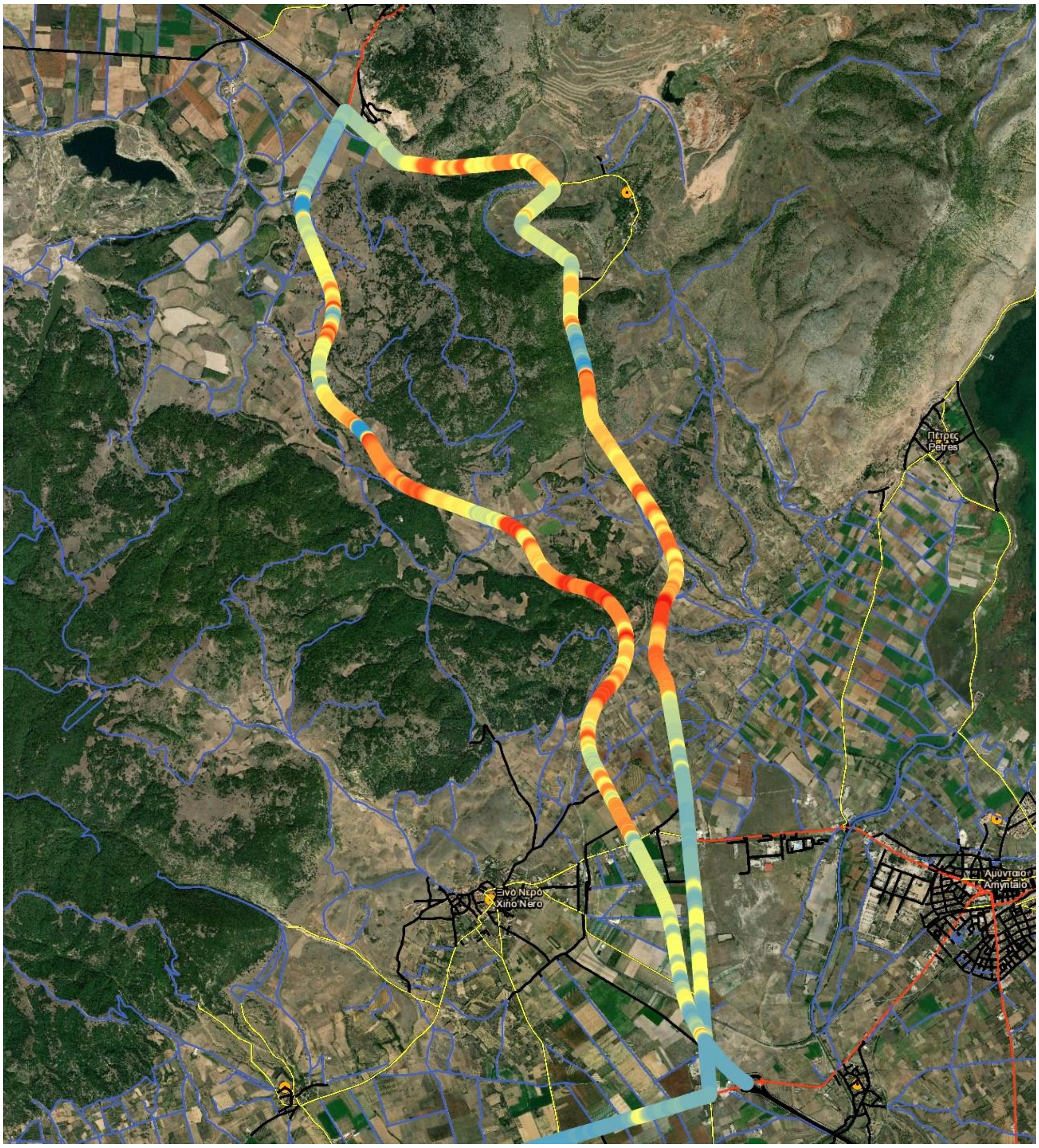


Figure 39. Road crossing suitability at the logarithmic scale derived from ground crossing data after Maxent modeling, in the **New and Old highway from Amydaio to Vevi.** Warmer colors indicate higher suitability for crossing.

Figure 40. Road crossing suitability at the logarithmic scale derived from ground crossing data after Maxent modeling, in the road segment from **Xino Nero to Sklethro.** Warmer colors indicate higher suitability for crossing.

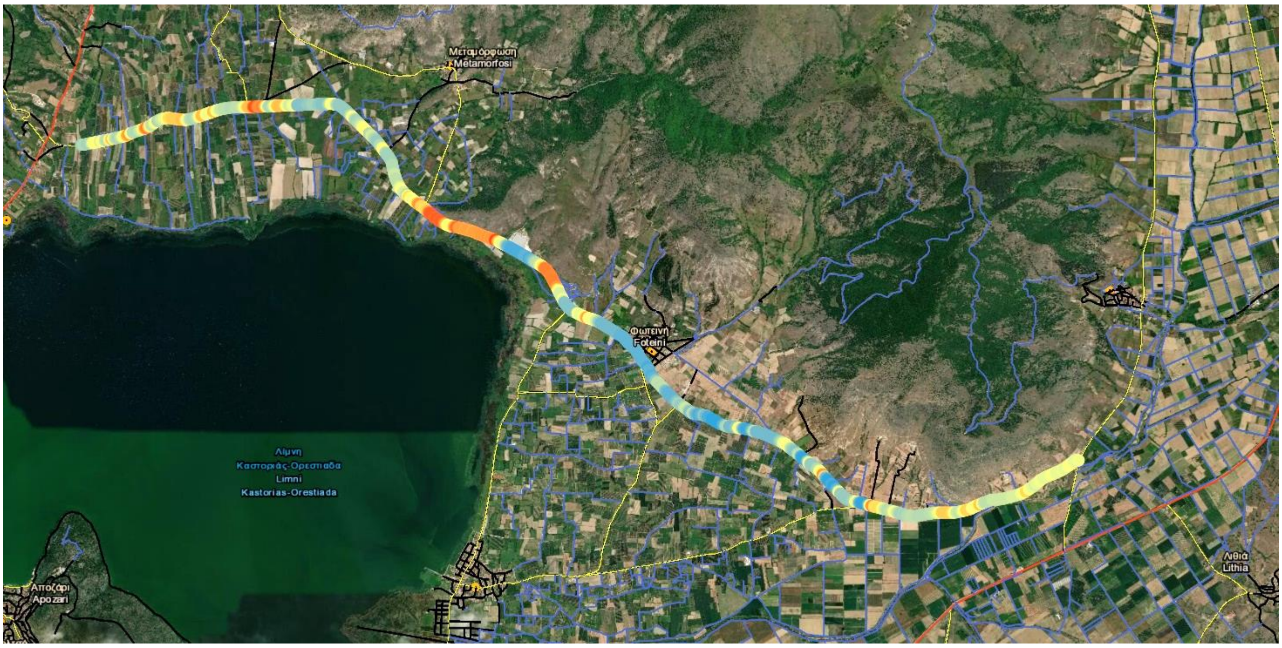


Figure 41. Road crossing suitability at the logarithmic scale derived from ground crossing data after Maxent modeling, in the road segment from **Foteini-Metamorphosi** road segment**.** Warmer colors indicate higher suitability for crossing.

12. Collision Risk Analysis

A third run of MAXENT algorithm was performed to analyze and predict collision risk areas by using all prior information. Analysis was undertaken exclusively at the road line surface of the road segments under evaluation.

Each road point from each road segment was loaded with information derived from previous analysis (assigned data by location- extract multi values to points).

Thus, bear connectivity analysis and bear crossing analysis were used as **prior information** and encompassed all environmental parameters that influence relative crossing probabilities or habitat relative suitability. Both relative suitability maps produced (connectivity map and bear crossing suitability maps) were rescaled by logarithmic function (scale from 0 to 1).

Rescaling of the connectivity map was achieved in a reversed way i.e. the highest suitability for bear connectivity had a value of 1 and the lowest a value of 0 (as connectivity analysis form Linkage mapper produces resistance maps). All other predictor variables related to road characteristics, traffic and speed metrics were retained to their original values.

Other information included a) curvature of the road points at various scales (0, 50, 100, 200m) b) traffic characteristics per segment c) road characteristics. We only used predictor variables that they did not originally used in priors (connectivity map and bear crossing suitability maps).

We also created three more **compound variables** that combine, the results of the two prior bear suitability variables, as to achieve inclusion of both priors in the analysis. The first compound variable (CS_03T_07C) was created (raster calculator) by giving a weight of 0.3 to the connectivity suitability prior and 0.7 to the crossing suitability prior, as the crossings related to tagged animals were approximately one third of those used for bear crossing analysis. The second compound variable (CS_05T_05C) weighted arbitrarily and equally the two suitability maps (connectivity and road crossing both having a weight of 0.5). The third compound variable (CS_07T_03C) used the reversed weights than the first compound variable.

Then, road points (10m interval) were converted to raster (10m grid cell size) with values taken from the predictor variables at the exact point. In this way MAXENT **analyzes only data that correspond exactly to the road surface points**.

12.1Variable correlation Matrix (bear accidents analysis).

As with the rest of the two previous MAXENT analyses caution was taken as for predictor variables entering each algorithm run not be highly correlated otherwise model outputs produced in MAXENT (or any kind of species distribution models) can be overfitted and not valid. Thus, we created a correlation matrix to avoid the simultaneous inclusion in the models of highly correlated predictors and thus avoid multicollinearity of data. High values of Pearson correlation (>0.7) appear in red fonts.

Table 15. Correlation matrix for predictors used in MAXENT 3.4.1 for analyzing bear accident data

	ADTRAFFIC	AVESPEED	VMAX	GAPTIME	VSS85	PERC_90	PERC_100	ROADWIDTH	GUARDNSEXT	EMBDNSEXTC	ORYGDNSEXT	CURVAVE200	CURVAVE100	CURVAVE50M	CURVAKERNE	VERG10EXTC	CONNECTLOG	GWRSUITCRS	CST03T_07C	CST05T_05C	CS07T_03C
ADTRAFFIC	1.00																				
AVESPEED	0.96	1.00																			
VMAX	0.73	0.83	1.00																		
GAPTIME	-1.00	-0.96	-0.77	1.00																	
VSS85	0.92	0.97	0.93	-0.94	1.00																
PERC_90	0.96	0.98	0.87	-0.97	0.99	1.00															
PERC_100	0.96	0.96	0.85	-0.97	0.98	1.00	1.00														
ROADWIDTH	0.89	0.89	0.85	-0.91	0.96	0.96	0.98	1.00													
GUARDNSEXT	0.69	0.67	0.51	-0.69	0.66	0.69	0.69	0.67	1.00												
EMBDNSEXTC	0.57	0.57	0.43	-0.56	0.54	0.56	0.56	0.52	0.87	1.00											
ORYGDNSEXT	0.14	0.20	0.13	-0.13	0.16	0.16	0.14	0.11	0.02	0.02	1.00										
CURVAVE200	-0.04	-0.05	-0.17	0.05	-0.11	-0.09	-0.09	-0.12	0.05	0.09	0.18	1.00									
CURVAVE100	-0.04	-0.05	-0.16	0.05	-0.11	-0.08	-0.09	-0.12	0.05	0.09	0.18	0.99	1.00								
CURVAVE50M	-0.03	-0.05	-0.16	0.05	-0.10	-0.08	-0.08	-0.11	0.05	0.08	0.18	0.99	1.00	1.00							
CURVAKERNE	-0.03	-0.05	-0.16	0.05	-0.10	-0.08	-0.08	-0.11	0.05	0.09	0.18	0.99	1.00	1.00	1.00						
VERG10EXTC	-0.16	-0.17	-0.26	0.18	-0.24	-0.22	-0.24	-0.28	-0.15	-0.04	0.04	0.04	0.04	0.04	0.04	1.00					
CONNECTLOG	0.04	0.06	-0.21	0.00	-0.05	-0.01	-0.02	-0.08	0.28	0.29	0.33	0.24	0.24	0.24	0.24	0.06	1.00				
GWRSUITCRS	0.30	0.32	0.09	-0.28	0.22	0.26	0.24	0.16	0.35	0.35	0.34	0.13	0.13	0.13	0.13	0.46	0.47	1.00			
CST03T_07C	0.26	0.28	0.00	-0.22	0.16	0.20	0.18	0.10	0.37	0.38	0.38	0.18	0.18	0.18	0.18	0.39	0.71	0.96	1.00		
CST05T_05C	0.20	0.23	-0.06	-0.16	0.10	0.15	0.13	0.05	0.37	0.37	0.39	0.22	0.21	0.21	0.21	0.31	0.85	0.86	0.97	1.00	
CS07T_03C	0.14	0.16	-0.13	-0.09	0.04	0.08	0.06	0.00	0.34	0.35	0.38	0.24	0.23	0.23	0.23	0.21	0.95	0.72	0.89	0.97	1.00

12.2 MAXENT Runs for brown bear accidents data- Parametrization and results

Maxent run for bear accident data was undertaken only over road points (10m interval). All bear crossing points were assigned spatially (slightly moved at a 90 degree from their original mapped position) and over the center of each road segment (i.e. to be inside grid cells). Thus, MAXENT evaluated all relevant parameters (predictors of accident distribution) using their values that corresponded exactly to the **centerline of the road segments** in concern. Spatial resolution was kept at 10m (equal to available grid cell size) to achieve the most spatial accuracy possible.

Maximum number of **permitted iterations** was set to 5000. **Regularization multiplier** was set to the default value of 1. **Prevalence** was set to default value, τ= 0.5 as the species is a generalist and common in the study area or otherwise it in not known for the distribution of risk collision. The default option (auto) was set for feature selection (linear, quadratic, product and hinge selected).

Maxent was run in a set of preliminary models using as validation method the "random test percentage" option (with one replication per run) to permit several repetitions with many combinations of variables in a reasonably achieved analysis time. 25% of the provided accidents were used each time as test set .First ,the Maxent algorithm was run a series univariate models for each one of all predictor variables by using the same train/data set as the random seed selection was disabled. The best (highest training and test AUC values) univariate (single variable) model was set as the baseline model.

Table 16 Results from the explorative **univariate** MAXENT models

Variable	Training AUC	Test AUC
Suitcross (Bear crossing suitability from telemetry data)	0.786	0.750
Connect (Connectivity suitability from crossing point data)	0.769	0.849
CS_03T_07C (Bear crossing suitability w=0.3 – Connectivity suitability w=0.7)	0.797	0.777
CS_05T_05C (Bear crossing suitability w=0.5 – Connectivity suitability w=0.5)	0.802	0.789
CS_07T_03C (Bear crossing suitability w=0.7 – Connectivity suitability w=0.3)	0.802	0.809
VEG10 dns (density of verges up to 10m)	0.537	0.407
ADT traffic volume	0.697	0.649
Avespeed, average speed	0.681	0.684
Gaptime, interval of traffic	0.675	0.660
Vmax, maximum speed	0.667	0.752
Vss85, sequence speed at upper 15% speed quantile	0.667	0.722
Perc90, percentage of cars above 90 km/hr	0.675	0.660
Perc100, percentage of cars above 100km/hr	0.667	0.722
EMBdns, Density of embankments	0.726	0.628
Orygdns, density of trenches	0.534	0.531
Guardraildns, density of guard rails	0.805	0.659
Roadwidth, road width	0.667	0.772
Curve, spot curvature	0.696	0.601
Curvave50, average road curvature at 50m	0.682	0.612
Curvave100, average road curvature at 50m	0.685	0.612
Curvave200, average road curvature at 50m	0.675	0.589

All variables were informative and increased prediction ability of the model above a null model except the Verg10dns, however a similar variable (Verg20Dns) played a critical role in shaping bear crossing suitability thus the predictor is already present in the priors that refer to crossing suitability. The most informative variables were the **prior** variables related to bear habitat connectivity and crossing suitability and their combinations. In the other hand although guard rail density is a particularly good training variable appears to have quite low effectiveness on predicting accidents.

A stepwise forward procedure was then used to build the final candidate models. We excluded from further runs variables that could reduce the overall test gain and the overall test AUC value, compromising the predictive value of the model. Highly correlated variables were not used for the same run. All final variable combinations (i.e. those achieved the highest combinations of training and test AUC values) were run as replicates for **24 repetitions** (i.e. equal to the number of accidents, as to use all location in the test sets). The cross-validation method was used to validate the models. Outputs were created in the raw format.

From the initial set of 21 predictors tested, only 9 were included in the final candidate models in combinations of three or four. The procedure described provided 10 final candidate models. Candidate models had very similar AUC values. We used ENM Tools to select the best model amongst those candidate output models using information criteria.

Table 17 Model selection. Variables used in the final 10 top candidate models (25% test set, in a single replication with the same test set for comparisons)

	MODEL 1	**MODEL 2**	**MODEL 3**	**MODEL 4**	**MODEL 5**	**MODEL 6**	**MODEL 7**	**MODEL 8**	**MODEL 9**	**MODEL 10**
CS_07T_03C		X		X					X	X
CS_05T_05C	X		X		X	X				
CS_03T_07C							X	X		
VEG10 dns					X				X	
Avespeed			X	X				X		
Gaptime	X	X			X		X		X	
Perc90,										X
Perc100,						X				
Curvave100,	X	X	X	X	X	X	X	X	X	X
Train set **AUC**	**0.843**	**0.842**	**0.846**	**0.851**	**0.844**	**0.846**	**0.845**	**0.847**	**0.844**	**0.847**
Test set **AUC**	**0.834**	**0.845**	**0.827**	**0.836**	**0.836**	**0.831**	**0.819**	**0.815**	**0.845**	**0.841**
Model code	R27	R28	R32	R34	R29	R31	RS25	R33	R30	R6

Candidate models included all three combined crossing suitability variables (priors). The weighted combinations of the telemetry and crossing models (i.e. in a single variable) permitted the inclusion of non-correlated predictors in the models that substantially increased their performance as expressed in the high values of both training and test AUC achieved, despite the very low sample size (n=24). Apart from the **combined crossing suitability, speed, traffic volume and average road curvature at 100m** contributed to the collision risk relative probability.

As candidate models although had similar AUC values, the differed in a critical parameter i.e. the habitat-crossing suitability priors.

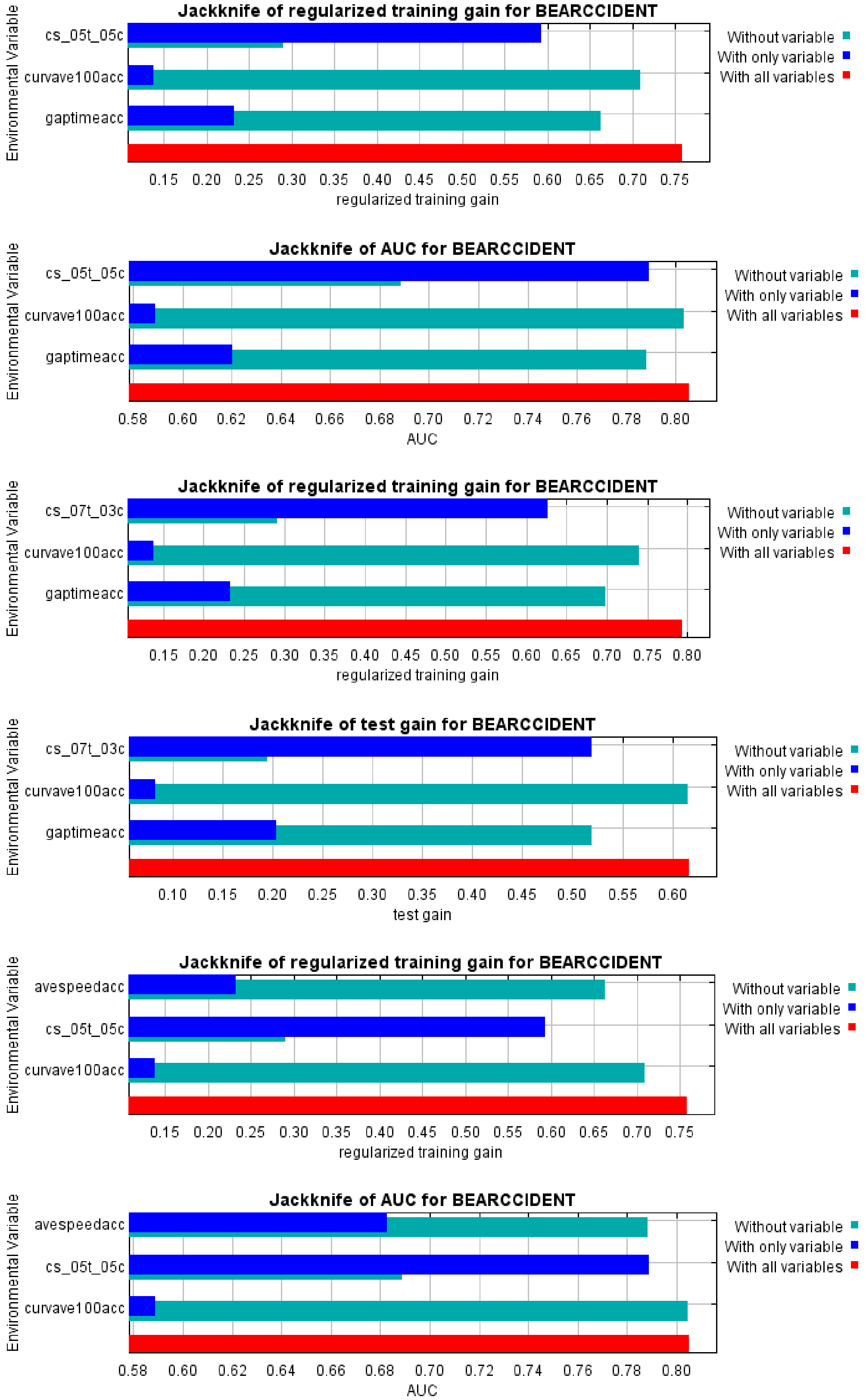
Thus, apart from using information criteria to select for the "best" models, we also calculated **Akaike weights w_i[25]**, in order to combine (average) the best models and produce a final raster risk map that averaged the information provided by those models according to their weights. We **estimated weights only for the top-three top models** as further weighting is practically meaningless as the sum of weights for the top-three models exceeded in most combinations the value of 0.975

Table 18. ENM Tools diagnostics for the top candidate models. Classification of models according to their performance was performed with the AICc information criterion which is most suitable for small samples.

	Log Likelihood	Param.	Sample size	AIC	AICc	BIC	ΔAICc	Δi	Wi
Model1	-180.847	6	24	373.695	378.636	380.763	0,000	1	**0,705**
Model2	-179.978	7	24	373.956	380.956	382.202	2,320	0,313	**0,221**
Model3	-180.599	7	24	375.199	382.199	383.446	3,563	0,168	**0,119**
Model4	-179.534	8	24	375.068	384.668	384.492	6,032		
Model5	-180.695	8	24	377.391	386.991	386.815	8,355		
Model6	-180.756	8	24	377.512	387.112	386.937	8,476		
Model7	-181.398	8	24	378.797	388.397	388.222	9,761		
Model8	-181.261	9	24	380.522	393.379	391.125	14,743		
Model9	-179.940	10	24	379.881	396.804	391.662	18,168		
Model10	-179.761	11	24	381.522	403.522	394.481	24,886		

Model outputs including prediction risk maps were derived after 24 replications for each variable combination with the random seed selection enabled (i.e. all accidents were used for testing the model). In the following figures we provide results and variable response curves from the top candidate models that performed the best (lowest AICc value).

[25] Symonds, M.R.E., Moussalli, A. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behav Ecol Sociobiol* **65,** 13–21 (2011). https://doi.org/10.1007/s00265-010-1037-6



Final Model 1
Akaike weight = 0.705

Model 2
Akaike weight = 0.221

Model 3
Akaike weight = 0.119

Figure 42. Jackknife on regularized training data gain, and test AUC for predictor variables for the three models selected for averaging.

In all three models the most important variable was the combined crossing suitability and especially the one that equally combines crossing probabilities from telemetry and ground surveys as it appears in two of the three models. The next important variable is the **traffic volume** expressed here by the **Gaptime** traffic variable and **average speed** that appear in one of the three final models. **Average Curvature at 100 radii** was included as the third most important variable in all three final models.

The following average response curves from the replicate runs provide useful information on how the predictor variables affect collision risk. Each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables.

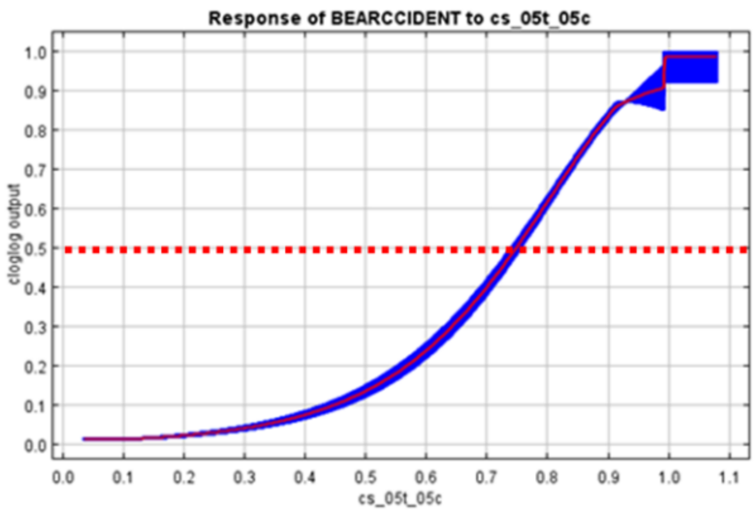


Figure 43 Average response curve for the **combined bear crossing suitability.**
The curve fit is identical for all three final models. If we consider as an arbitrary threshold probability for collision the commonly used value of 0.5 in the logarithmic scale (the default value that Maxent also uses to evaluate predictions) we can conclude that collision risk increases when bear crossing suitability rise high and **above a value of approximately 0.75** (in a scale of 0-1).

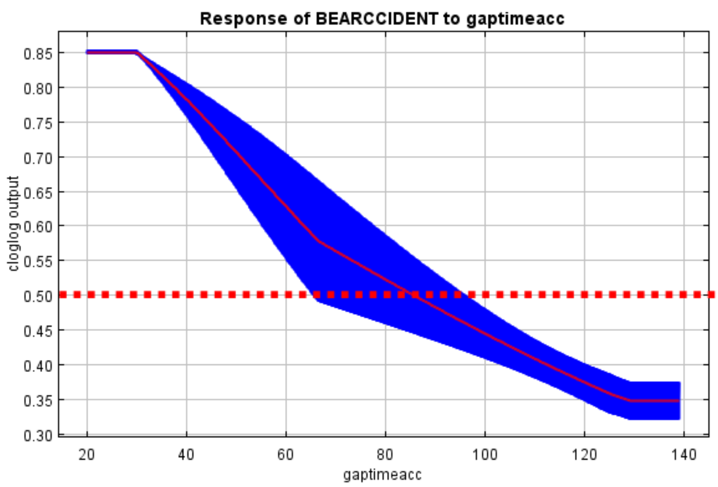


Figure 44. Average response curve for the **GapTime** variable (**Traffic volume** index). The curve fit is identical for both final models that use this variable.
Collision risk is greatly reduced with the increase of GapTIme , i.e. with the reduction of traffic volume. When **GapTime** is approximately **above 90sec** the collision risk is reduced under the 0.5 threshold

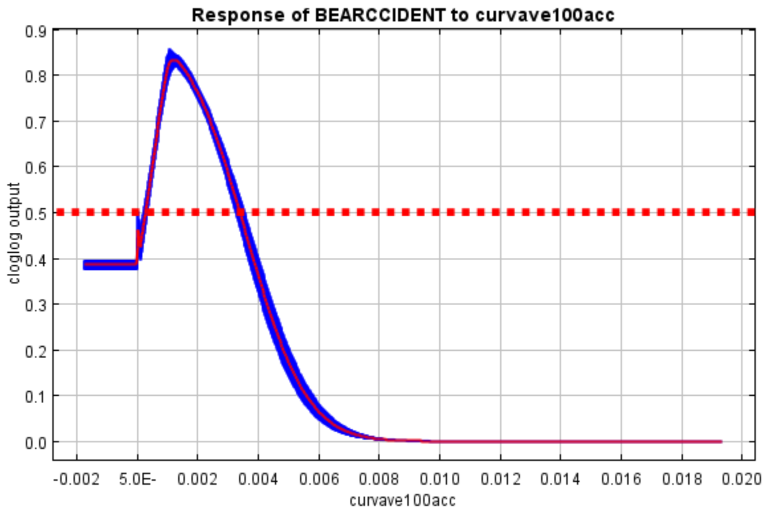


Figure 45. Response curve for the **Average Road Curvature at 100m**.

The curve fit appear is identical for all three final models.

Collision risk increases above 0.5 probability for a certain value range of road curvature i.e. between **0.00096 and approximately 0.0029** and peaks around 0.002 value, then drops rapidly at higher values. This practically means that most dangerous spots seem to be the **transient area between a straight part of the road before or soon after a turn where higher speeds mix with a reduced visibility**

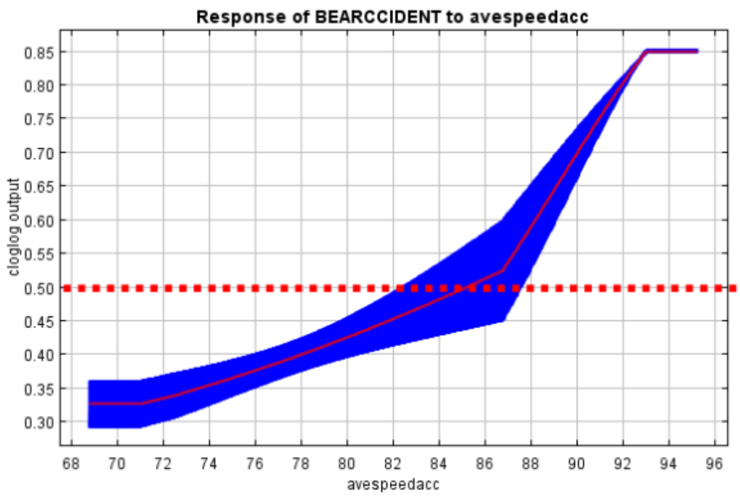


Figure 46. Average response curve for **Average Speed**.

Collision risk is **increasing sharply** and above the 0.5 threshold when average speed exceeds a value of approximately **85 km.**

12.3 Collision risk predictions per point and road segments.

For each point of the road segments evaluated values from the three final models were assigned (extraction of multi risk raster values to points). The **combined risk** was calculated using all three models after weighting with their respective Akaike weights (i.e. ***Combined risk = 0.706*riskMOdel1+0.221*riskModel2+0.119*riskModel3***).

The collision risk was provided in RAW standardized format, meaning that ***all points/segments are ranked comparatively together from a lowest to a higher value***. All values are summing up to value 1. The natural Jenks method was used for risk classification in 4 classes.

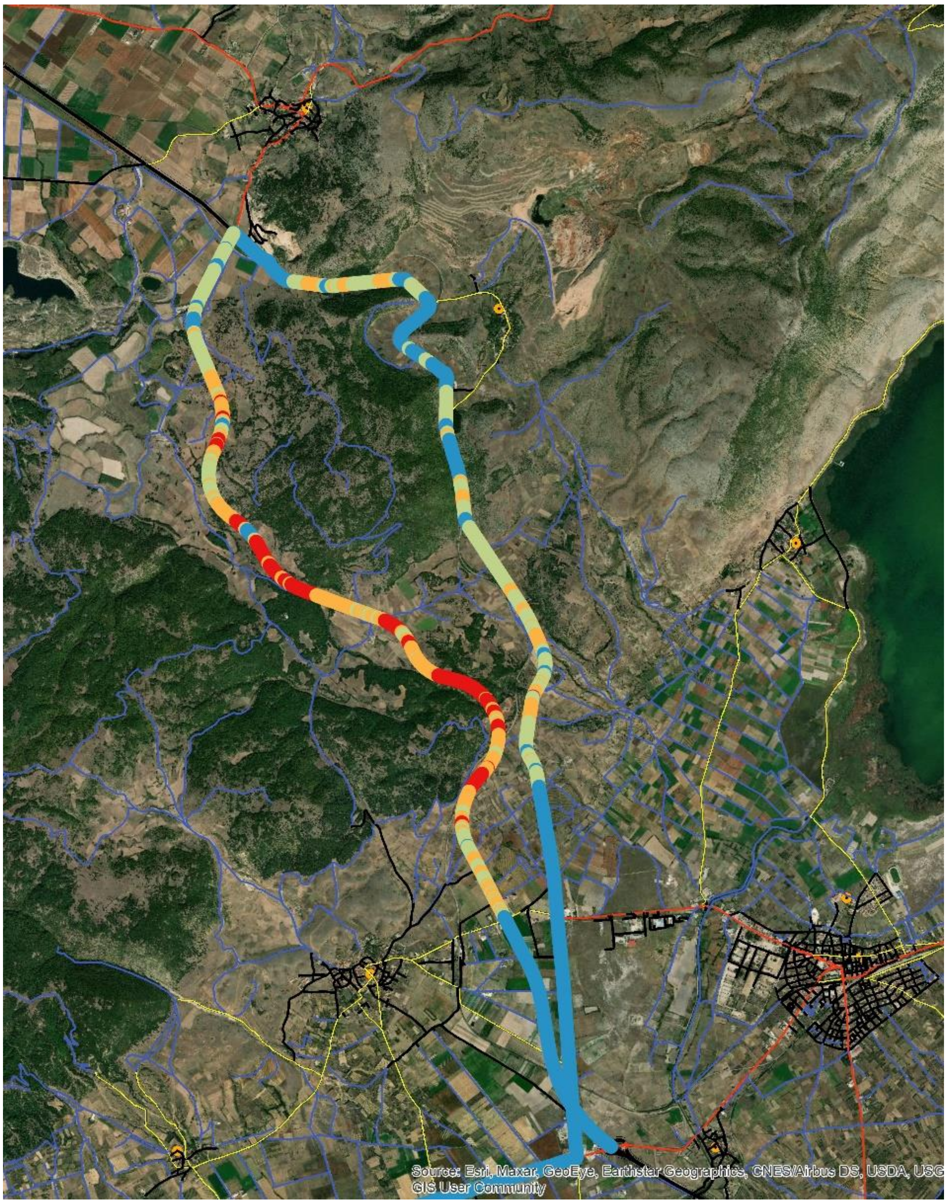


Figure 47. Collision risk for the **New and Old highway from Amydaio to Vevi.** Warmer colors indicate higher risk

Figure 48. Collision risk for the **Xino Nero- Sklethro segments** Warmer colors indicate higher risk

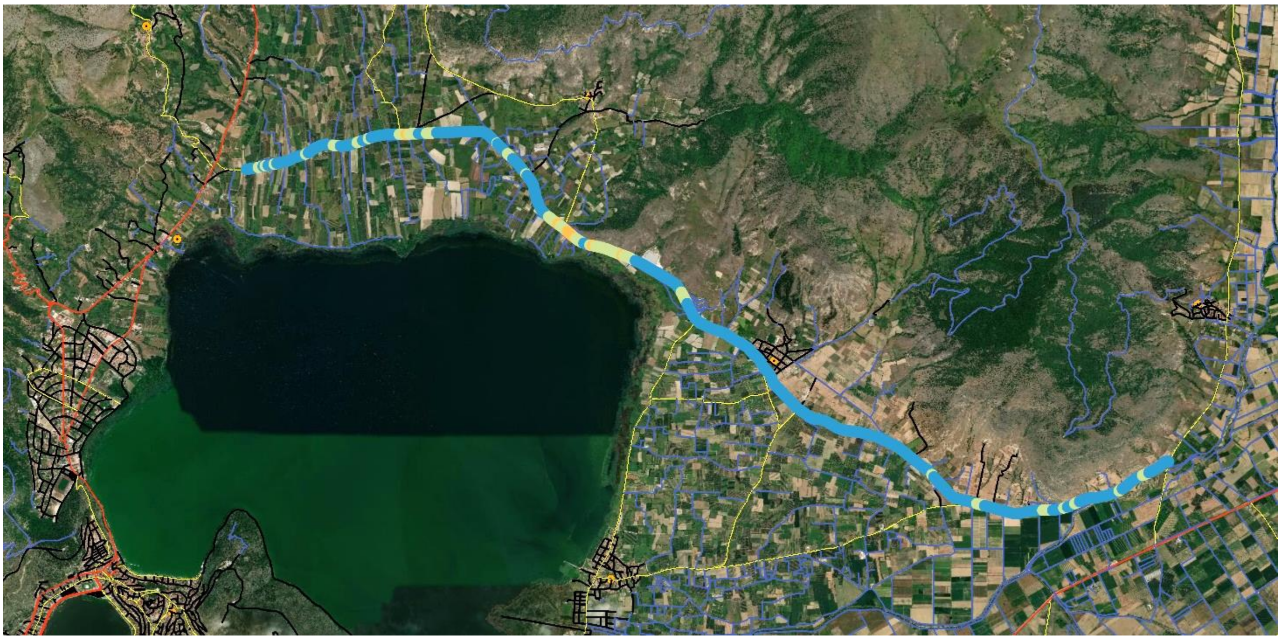


Figure 49. Collision risk for the **Foteini-Metamorphosi segment.** Warmer colors indicate higher risk

12.4 Summary on factors affecting number of accidents per road segment

The procedure followed, revealed those factors that may affect bear collision risk for a certain spatial point over a road surface and proposed critical values or ranges that increase risk over a certain (but relatively arbitrary) threshold. Based on these values we created a table that summarizes results from all 5 segments and encompasses those critical values into **new, more informative variables.**

Table 19, Summary of highly importance variables affecting number of accidents and overall collision risk per road segmetns

	Average speed km/hr	**Average gap time,** sec	**Percentage of points >0.75** of combined crossing suitability[26]	Percentage of points with average **Curvature 100m at high-risk class**	Number of known **Bear accidents**	**Cumulative sum of collision risk**
Foteini-Metamprphosi	*71*	*129*	17.8%	26.1%	**3**	**0.114**
Aetos- Sklethro	*77*	129	28.8%	16.9%	**3**	**0.168**
Pedino-Aetos	74	121	0%	1.6%	**1**	**0.012**
Old highway Amydaio-Vevi	80.5	103	42%	13.6%	**3**	**0.218**
New highway Amydaio-Vevi	93	30	43%	52.8%	**14**	**0.581**

Although the sample is very small, **we attempted a multiple regression** to conclude on the importance of those new highly informative variables to define the number of accidents and explain the high heterogeneity on their numbers amongst different sectors of the study area. Thus, the sample size here (n=5) is the road segment itself rather than single road points.

We run several multiple regression models because a) Average speed and Average GapTime are highly corelated variables and b) we could include only two variables per run because of the very small sample size.

As expected, all models failed to produce statistically significant results even if only two variables were used. The only model that provided nearly significant results and only in the 90% significance level (F=87,7, P= 0.011) was the one that included Curvature percentage of the high-risk class in combination with a traffic volume metric (Gaptime).

[26] For simplicity we used only the CR05t_05c combined suitability which appeared the most influential combination with a weight of 0.709

Table 20. Results from regression analysis (F=87,7, P= 0.011*)

	b-coefficients	*se*	*t*	*P*
Ordinate	8,985	2,397	3,748	0,064*
GAP TIME	-0,069	0,016	**-4,235**	0,051*
Percentage of high-risk curvature class	0,132	0,036	**3,690**	0,066*

(*) Significance at 90% level

The result of this exploratory analysis shows that characteristics of the road (traffic and shape) may play the most important role compared to bear suitability in shaping collision risk at the landscape level in a given area with bear presence.

13.Candidate locations for AVC Installment

To select candidate location for establishment of the AVC system several information were combined. A table was created with all data available to select amongst a wide array of possible sites that included all field information and results from statistical analysis and risk modelling. In most of the candidate locations at least one camera trap was deployed (range 1-3). RAI indexes were calculated after **merging and grouping cameras per AVC location**. Some candidate positions did not have camera trap data, because either information on accidents close to those sites became very lately available or current analysis revealed high risk for collision.

The table contains the following information:

1. **Name** of the Location expressed as **Av**xxx
2. **Segment**: Name of the road segment
3. **Approximate coordinates** in UTM system (XY in meters -WGS_1984_UTM_Zone_34N)
4. **Collision risk**: Value from the combined model corresponding to the closest maximum value at a radius of 100m.
5. **Collision class**: The most common risk class or classes in the area at a radius of 100m.
6. **Wildlife path located**: Number of identifiable wildlife paths crossing the road
7. **RAI population index for brown bears** related to crossings (CRRS-BEAR-POP-RAI)
8. **RAI population index for all large mammals** (pooled data) only for photo captures related to crossings (CRRS-ALL-POP-RAI)
9. **RAI population index for wild boar** related to crossings (CRRS-WBOAR-POP-RAI)
10. **RAI population index for wolf** - related to crossings (CRRS-WOLF-POP-RAI)
11. **RAI population index for roe deer** related to crossings (CRRS-ROEAD-POP-RAI)
12. **Visibility of the road**. Classification according to road curvature:
13. **Terrain**: Description related to the presence of embankments, trenches or flat terrain.
14. **Guard rails**: Presence of guard rails (yes, no, both, one side)
15. **Human presence**: Low, med, high in relation mostly to the presence of livestock
16. **Practicability**: The easiness to set an AVC system in relation to terrain, vegetation and functionality of the system

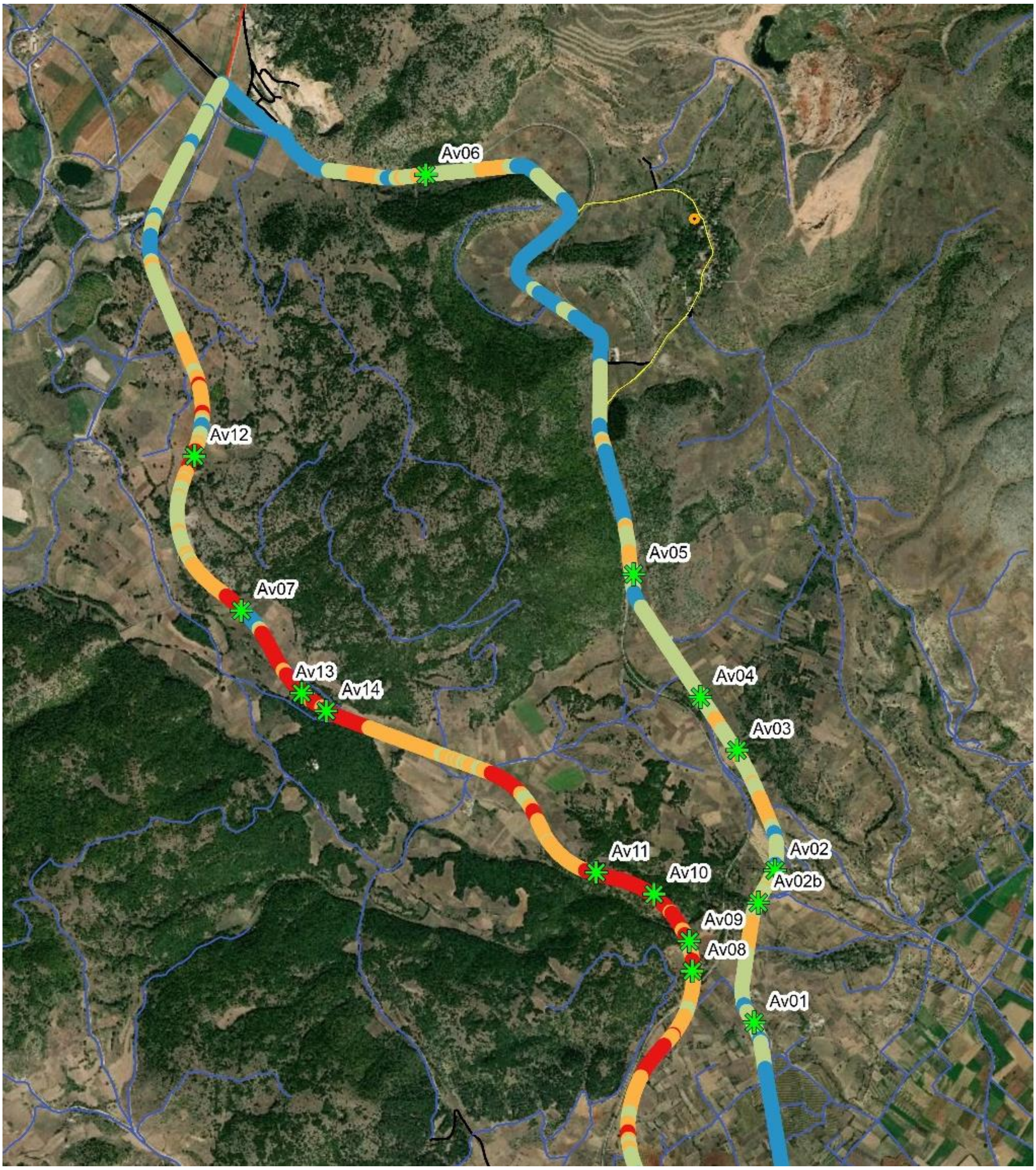


Figure 50. Collision risk and Candidate AVC Positions for the New and Old highway from Amydaio to Vevi.

Figure 51. Collision risk and Candidate AVC Positions for the Aetos- Sklethro road segment

Figure 52. Collision risk and Candidate AVC Positions for the **Foteini – Metamorphosi** road segment

13.1 Proposed sites for AVC installation- information tables per site

Table 21. Collision risk, L. mammal occurrence and technical information for candidate location -Av01

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS
Av01	OLDHWY	554308	4506692	8,2	**0,0**	0,0	4,9	3,3	**0,000430**	2 &3

PATHS	#PATHS	Guard rails	Terrain	HUMAN	Practicability	visibility
YES	3	NO	FLAT &TRENCH	LOW	HIGH	TURN, BAD VISIBILITY




Table 22. Collision risk, L. mammal and technical information for candidate location -Av02

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av02	OLDHWY	554425	4507543	13,8	**0,6**	5,0	8,2	0,0	**0,000450**	2 &3	YES	2

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	FLAT &TRENCH	LOW	HIGH	TURN, BAD VISIBILITY




Table 23. Collision risk, L. mammal and technical information for candidate location -Av02b

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av02B	OLDHWY	554331	4507303	N/A	**N/A**	N/A	N/A	N/A	**0,021700***	3&4	YES	2

(*)Highest collision risk in study area

Guard rails	Terrain	HUMAN	Practicability	visibility
BOTH SIDES	EMBANKMENTS- BOTH	LOW	MEDIUM	Medium VISIBILITY, VERGES

Table 24. Collision risk, L. mammal and technical information for candidate location -Av03

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av03	OLDHWY	554214	4508215	5,8	**2,9**	0,0	2,9	0,0	**0,000570**	2&3	YES	3

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	FLAT &TRENCH	LOW	HIGH	MEDIUM VISIBILITY

Table 25. Collision risk, L. mammal and technical information for candidate location -Av04

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av04	OLDHWY	554008	4508513	3,3	**3,3**	0,0	0,0	0,0	**0,000280**	2	YES	3

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	LOW EMBANKMENT&FLAT	MED	HIGH	MEDIUM VISIBILITY, VERGES

Table 26. Collision risk, L. mammal and technical information for candidate location -Av05

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av05	OLDHWY	553635	4509200	96,6	**0,8**	0,0	91,6	4,2	**0,000490**	2&3	YES, HIGHLY USED	3

Guard rails	**Terrain**	**HUMAN**	**Practicability**	**visibility**
NO	FLAT&TRENCH	MED (LVST)	HIGH	MEDIUM VISIBILITY




Table 27. Collision risk, L. mammal and technical information for candidate location -Av06

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av06	OLDHWY	552473	4511438	5,7	**0,0**	0,0	5,7	0,0	**0,000650**	3	YES	1

Guard rails	**Terrain**	**HUMAN**	**Practicability**	**visibility**
NO	LOW EMBANKMENT&LOW TRENCH	MED (LVST)	MEDIUM	MEDIUM VISIBILITY, VERGES




Table 28. Collision risk, L. mammal and technical information for candidate location -Av07

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av07	NEWHWY	551441	4508997	101,9	**1,9**	0,6	94,2	5,2	**0,001400**	3&4	YES, HIGHLY USED	2

Guard rails	Terrain	HUMAN	Practicability	visibility
BOTH SIDES WITH OPENING	LOW EMBANKMENT&TRENCH	LOW	HIGH- MEDIUM	TURN, BAD VISIBILITY




Table 29. Collision risk, L. mammal and technical information for candidate location -Av08

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av08	NEWHWY	553962	4506980	9,7	**4,8**	0,0	1,6	3,2	**0,001260**	4	YES	1

Guard rails	Terrain	HUMAN	Practicability	visibility
YES -BOTH	EMBANKMENT& LOW TRENCH/FLAT	LOW	HIGH	TURN, BAD VISIBILITY




Table 30. Collision risk, L. mammal and technical information for candidate location -Av09

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av09	NEWHWY	553944	4507146	4,1	**2,0**	0,0	0,0	2,0	**0,001130**	4	YES	1

Guard rails	Terrain	HUMAN	Practicability	visibility
YES - WITH OPENING	LOW EMBANKMENT& TRENCH	LOW	HIGH	TURN, BAD VISIBILITY

Table 31. Collision risk, L. mammal and technical information for candidate location -Av010

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av10	NEWHWY	553749	4507409	0,0	**0,0**	0,0	0,0	0,0	**0,001210**	4	YES (ALSO WIDESRPEAD CROSSES)	2

Guard rails	Terrain	HUMAN	Practicability	visibility
BOTH SIDES	EMBANKMENT&FLAT	LOW	HIGH-MEDIUM	TURN, BAD VISIBILITY




Table 32. Collision risk, L. mammal and technical information for candidate location -Av11

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av11	NEWHWY	553425	4507532	9,7	**0,0**	0,0	8,3	1,4	**0,000149**	3&4	YES (ALSO WIDESRPEAD CROSSES)	1

Guard rails	Terrain	HUMAN	Practicability	visibility
YES - WITH OPENING	LOW EMBANKMENT& TRENCH/FLAT	LOW	HIGH	TURN, BAD VISIBILITY




Table 33. Collision risk, L. mammal and technical information for candidate location -Av12

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av12	NEWHWY	551178	4509862	N/A	**N/A**	N/A	N/A	N/A	**0,001480**	3&4	YES (ALSO WIDESRPEAD CROSSES)	2

Guard rails	Terrain	HUMAN	Practicability	visibility
YES - WITH OPENINGS	EMBANKMENT&FLAT	MED (LVST)	HIGH	TURN, BAD VISIBILITY




Table 33. Collision risk, L. mammal and technical information for candidate location -Av13

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av13	NEWHWY	551776	4508536	33,7	**1,1**	1,1	29,2	2,2	**0,001247**	4	YES, HIGHLY USED	3

Guard rails	Terrain	HUMAN	Practicability	visibility
YES IN EMBANKMENTS NOT IN TRENCHES	TRENCHES-BOTH	LOW	HIGH	TURN, BAD VISIBILITY




Table 34. Collision risk, L. mammal and technical information for candidate location -Av14

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av14	NEWHWY	551915	4508434	6,0	**2,7**	0,0	2,7	0,7	**0,001430**	4	YES	3

Guard rails	Terrain	HUMAN	Practicability	visibility
BOTH SIDES	EMBANKMENT&FLAT	LOW	MEDIUM	TURN, BAD VISIBILITY

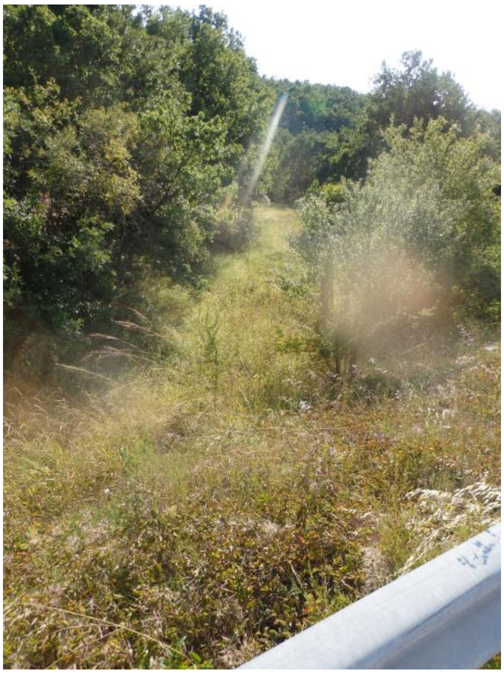


Table 35. Collision risk, L. mammal and technical information for candidate location -Av15

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av15	SKLHTHRO	544150	4498661	31,5	**20,2**	7,3	0,6	3,4	**0,000580**	2 &3	YES	1

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	TURN, BAD VISIBILITY




Table 36. Collision risk, L. mammal and technical information for candidate location -Av16

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av16	SKLHTHRO	543480	4498279	23,0	**17,4**	3,3	0,6	1,7	**0,000580**	3	YES	2

Guard rails	Terrain	HUMAN	Practicability	visibility
ONE SIDE	EMBANKMENT& TRENCH	MED (LVST)	MEDIUM	STRAIGHT

Table 37. Collision risk, L. mammal and technical information for candidate location -Av17

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av17	SKLHTHRO	543271	4498116	27,9	**23,4**	3,6	1,0	0,0	**0,000580**	3	YES, HIGHLY USED	3

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	MEDIUM VISIBILITY

Table 38. Collision risk, L. mammal and technical information for candidate location -Av18

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
Av18	SKLHTHRO	543081	4498016	118,3	**51,6**	66,7	0,0	0,0	**0,000550**	2 &3	YES, HIGHLY USED	2

Guard rails	Terrain	HUMAN	Practicability	visibility
NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	TURN, BAD VISIBILITY

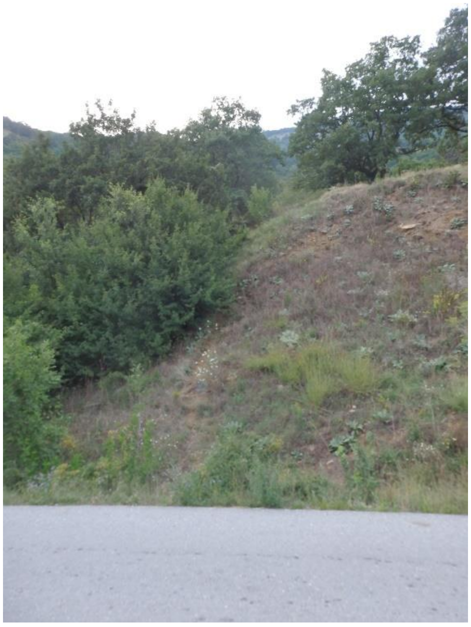


Table 39. Collision risk, L. mammal and technical information for candidate location -Av19

Name	SEGMENT	X	Y	RAI ALL	RAI BEAR	RAI WOLF	RAI WBOAR	RAI ROE	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS
AV19	FOTEINH	527100	4488998	11,5	**10,7**	0,0	0,0	0,8	**0,000570**	2 &3	YES, HIGHLY USED	1

Guard rails	**Terrain**	**HUMAN**	**Practicability**	**visibility**
NO	FLAT&TRENCH	LOW	MEDIUM	MEDIUM VISIBILITY, VERGES

13.2 Preliminary selection of Candidate AVC sites

We prioritized (draft evaluation) 8 from the 20 sites according to collision risk assessment and crossing frequency from brown bears and other large mammas per road segment. However, the final decisions need to also take account technical and administrative issues while a thorough evaluation of the report should run ahead from the project team before finalizing the positions. Sites **Av02 & Av02b**, **Av13 & Av14** and **Av 17 & Av18** are bonded together in the following table as they are close and a single AVC unit could be installed instead.

Name	SEGMENT	RAI ALL	RAI BEAR	COLLISION RISK	COLLISION CLASS	PATHS	#PATHS	Guard rails	Terrain	HUMAN	Pract.	visibility
Av01	OHWY	8,2	0,0	0,000430	2 &3	YES	3	NO	FLAT &TRENCH	LOW	HIGH	TURN, BAD VISIBILITY
Av02	OHWY	13,8	0,6	0,000450	2 &3	YES	2	NO	FLAT &TRENCH	LOW	HIGH	TURN, BAD VISIBILITY
Av02B	OHWY	N/A	N/A	0,021700	3&4	YES	2	BOTH SIDES	EMBANKMENTS-BOTH	LOW	MEDIUM	BAD VISIBILITY, VERGES
Av03	OHWY	5,8	2,9	0,000570	2&3	YES	3	NO	FLAT &TRENCH	LOW	HIGH	MEDIUM VISIBILITY
Av04	OHWY	3,3	3,3	0,000280	2	YES	3	NO	LOW EMBANKMENT& FLAT	MED	HIGH	MEDIUM VISIBILITY, VERGES
Av05	OHWY	96,6	0,8	0,000490	2&3	YES, HIGHLY USED	3	NO	FLAT&TRENCH	MED (LVST)	HIGH	MEDIUM VISIBILITY
Av06	OHWY	5,7	0,0	0,000650	3	YES	1	NO	LOW EMBANKMENT& LOW TRENCH	MED (LVST)	MEDIUM	MEDIUM VISIBILITY, VERGES
Av07	NWY	101,9	1,9	0,001400	3&4	YES, HIGHLY USED	2	BOTH SIDES WITH OPENING	LOW EMBANKMENT& TRENCH	LOW	HIGH-MEDIUM	TURN, BAD VISIBILITY
Av08	NWY	9,7	4,8	0,001260	4	YES	1	YES	EMBANKMENT& LOW TRENCH/FLAT	LOW	HIGH	TURN, BAD VISIBILITY
Av09	NWY	4,1	2,0	0,001130	4	YES	1	YES - WITH OPENING	LOW EMBANKMENT& TRENCH	LOW	HIGH	TURN, BAD VISIBILITY
Av10	NWY	0,0	0,0	0,001210	4	YES (ALSO WIDESRPEAD CROSSES)	2	BOTH SIDES	EMBANKMENT& FLAT	LOW	HIGH	TURN, BAD VISIBILITY
Av11	NWY	9,7	0,0	0,000149	3&4	YES (ALSO WIDESRPEAD CROSSES)	1	YES - WITH OPENING	LOW EMBANKMENT& TRENCH/FLAT	LOW	HIGH	TURN, BAD VISIBILITY
Av12	NWY	N/A	N/A	0,001480	3&4	YES (ALSO WIDESRPEAD CROSSES)	2	YES - WITH OPENINGS	EMBANKMENT& FLAT	MED (LVST)	HIGH	TURN, BAD VISIBILITY
Av13	NWY	33,7	1,1	0,001247	4	YES, HIGHLY USED	3	NO	TRENCHES-BOTH	LOW	HIGH	TURN, BAD VISIBILITY
Av14	NWY	6,0	2,7	0,001430	4	YES	3	BOTH SIDES	EMBANKMENT& FLAT	LOW	MEDIUM	TURN, BAD VISIBILITY
Av15	SKL	31,5	20,2	0,000580	2 &3	YES	1	NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	TURN, BAD VISIBILITY
Av16	SKL	23,0	17,4	0,000580	3	YES	2	ONE SIDE	EMBANKMENT& TRENCH	MED (LVST)	MEDIUM	STRAIGHT
Av17	SKL	27,9	23,4	0,000580	3	YES, HIGHLY USED	3	NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	MEDIUM VISIBILITY
Av18	SKL	118,3	51,6	0,000550	2 &3	YES, HIGHLY USED	2	NO	FLAT&TRENCH	HIGH(LVST)	MEDIUM	TURN, BAD VISIBILITY
AV19	FOT	11,5	10,7	0,000570	2 &3	YES, HIGHLY USED	1	NO	FLAT&TRENCH	LOW	MEDIUM	MEDIUM VISIBILITY, VERGES

Table 21. Preliminary prioritization of candidate AVC sites

14. Literature cited

- Andrén H (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355–366.
- EEA - European Environment Agency (2011) Landscape fragmentation in Europe. Joint EEA-FOE report (EEA Report no. 2/2011). Copenhagen: EEA. http://www.eea.europa.eu/publications/ landscape-fragmentation-in-europe. Accessed 5 October 2014
- Forman RTT, Alexander LE (1998) Roads and their major ecological effects. Annu Rev Ecol Syst 29:207–231
- Iuell B, Bekker GJ, Cuperus R,Dufek J, Fry G, Hicks C, Hlaváč V, Keller VB, Rossel C, Sangwine T, Torslov N, Wandall BM (ed) (2003) COST 341 - wildlife and traffic: an European handbook for identifying conflicts and designing solutions. KNNV Publishers
- Vitousek PM, Mooney HA, Lubchenco J, Melillo J (1997) Human domination of Earth's ecosystems. Science 27:494–499
- Primack RB (2012) Primer of conservation biology, 5th edn. Sinauer Associates, Sunderland
- Vaiškūnaitė R, Mierauskas P, Špakauskas V (2012) Biodiversity impact assessment in road development in Lithuania. Transport 27:187–195
- Underhill JE, Angold PG (2000) Effects of roads on wildlife in an intensively modified landscape. Environ Rev 8:21–39
- Fahrig L, Rytwinski T (2009) Effect of roads on animal abundance: an empirical review and synthesis. Ecol Soc 14:21
- Benítez-López A, Alkemade R, Verweij PA (2010) The impacts of roads and other infrastructure on mammal and bird populations: a metaanalysis. Biol Conserv 143:1307–1316
- Riley SPD, Pollinger JP, Sauvajot RM, York EC, Bromley C, Fuller TK, Wayne RK (2006) A southern California freeway is physical and social barrier to gene flow in carnivores. Mol Ecol 15:1733–1741
- Carvalho F, Mira A (2011) Comparing annual vertebrate road kills over two time periods, 9 years apart: a case study inMediterranean farmland. Eur J Wildl Res 57:157–174
- Clarke GP,White PCL, Harris S (1998) Effects of roads on badger Meles meles populations in south-west England. Biol Conserv 86:117–124
- Basille M, Van Moorter B, Herfindal I, Martin J, Linnell JDC, Odden J, Andersen R, Gaillard JM (2013) Selecting habitat to survive: the impact of road density on survival in a large carnivore. PLoS One 8:1–11

- Grilo C, Bissonette JA, Santos-Reis M (2009) Spatial-temporal patterns in Mediterranean carnivore road casaulties: consequences for mitigation. Biol Conserv 142:301–313
- Paquet PC (1993) Summary reference document: ecological studies of recolonizing wolves in the Central Canadian Rocky Mountains, Final Report, April 1989 to June 1993. John/Paul Associates
- Waser PM (1996) Patterns and consequences of dispersal in gregarious carnivores. In: Gittleman JL (ed) Carnivore behaviour, ecology and evolution. Cornell University Press, pp 267–295
- Taylor SK, Buergelt CD, Roelke-Parker ME, Homer BL, Rotstein DS (2002) Causes of mortality of free-ranging Florida panthers. JWildl Dis 38:107–114
- Kusak J, Huber D, Frkovic A (2000) The effects of traffic on large carnivore populations in Croatia. Bios Conserv 3:35–39
- Woodroffe G (1994) The otter. The Mammal Society.
- Ferreras P, Aldama JJ, Beltrán JF, Delibes M (1992) Rates and causes of mortality in a fragmented population of Iberian lynx Felis pardine Temminck 1824. Biol Conserv 61:197–202
- Sherwood B, Cutler D, Burton J (2003)Wildlife and roads: the ecological impact. Imperial College Press
- Baker PJ, Dowding CV, Molony SE, White PCL, Harris S (2007) Activity patterns of urban red foxes (Vulpes vulpes) reduce the risk of traffic-induced mortality. Behav Ecol 18:716–724
- Frantz AC, Pope LC, Etherington TR, Wilson GJ, Burkem T (2010) Using isolation-by-distance-based approaches to assess the barrier effect of linear landscape elements on badger (Meles meles) dispersal. Mol Ecol 19:1663–1674
- Huck M, Jędrzejewski W, Borowik T, Miłosz-Cielma M, Schmidt K, Jędrzejewska B, Nowak S, Mysłajek RW (2010) Habitat suitability, corridors and dispersal barriers for large carnivores in Poland. Acta Theriol 55:177–192
- Jackson ND, Fahrig L (2011) Relative effects of road mortality and decreased connectivity on population genetic diversity. Biol Conserv 144:3143–3148
- Gunson KE, Mountrakis G, Quackenbush LJ (2011) Spatial wildlifevehicle collision models: a review of current work and its application to transportation mitigation projects. Environ Manag 92:1074– 1082
- Virgós E, Telleria JL, Santos T (2002) A comparison on the response to forest fragmentation by medium-sized Iberian carnivores in central Spain. Biodivers Conserv 11:1063–1079
- Gehring TM, Swihart RK (2003) Body size, niche breadth, and ecologically scaled responses to habitat fragmentation: mammalian predators in an agricultural landscape. Biol Conserv 109:283–295
- Barthelmess E (2014) Spatial distribution of road-kills and factors influencing road mortality for mammals in Northern New York State. Biodivers Conserv 23:2491–2514

- Clevenger AP, Chruszcz B, Gunson KE (2003) Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biol Conserv 109:15–26
- Hilty JA, Lidicker WZ, Merenlender AM (2006) Corridor ecology: the science and practice of linking landscapes for biodiversity conservation. Island Press
- Hlaváč V, Anděl P (2001) On the permeability of roads for wildlife: a handbook. AOPK ČR, Praha
- Glista DJ, DeVault TL, DeWoody JA (2009) A review of mitigation measures for reducing wildlife mortality on roadways. Landsc Urban Plan 91:1–7
- Grilo C, Bissonette JA, Santos-Reis M (2008) Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. Biodivers Conserv 17:1685–1699
- Grilo C, Bissonette JA, Santos-Reis M (2009) Spatial-temporal patterns in Mediterranean carnivore road casaulties: consequences for mitigation. Biol Conserv 142:301–313.