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THE ROLE OF HABITAT CONNECTIVITY ON ROAD MORTALITY OF TAWNY OWLS

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ABSTRACT

Research of habitat fragmentation has revealed a large number of constraining effects on species, which represent a central issue for wildlife conservation. In this article we address an approach based on spatial models of tawny owl *Strix aluco*. The habitat is assessed in relation to species density and hotspots of road casualties. The data was collected in two years surveys, in the montado habitat and casualties along 40 km of the road network. Data was used to generate a density surface and the identification of casualties' hotspots. The density surface and the location of mortality clusters were used to model a spatial perspective of population likelihood and mortality. The results reveal evidences of increased habitat fragmentation and casualty occurrence. The results allow us a vision of transportation infrastructure near future consequences of development and suggestions for defragmentation actions.

Keywords: Connectivity, Fragmentation, Infrastructures network, Montado, Road kill, *Strix aluco*.

A FRAGMENTAÇÃO DO HABITAT NA MORTALIDADE DE CORUJAS POR COLISÕES RODOVIÁRIAS

RESUMO

A investigação sobre a fragmentação de habitats tem revelado um grande número de efeitos restritivos sobre espécies, sendo uma questão central para a conservação da vida selvagem. Neste artigo fazemos uma abordagem da conectividade baseada em modelos espaciais da coruja-do-mato *Strix aluco*. O habitat é avaliado nas relações com a densidade populacional e mortalidade por colisões em rodovias. Os dados foram recolhidos em dois anos de amostra, no habitat de montado e a mortalidade ao longo de 40 km da rede rodoviária. Os dados foram usados para gerar uma superfície de densidade populacional e identificação de pólos críticos de mortalidade. A densidade e os pólos de mortalidade foram usados para estimar numa perspectiva espacial o risco de

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mortalidade. Os resultados revelam evidências de fragmentação do habitat e o aumento da ocorrência de acidentes. Os resultados permitem perspectivar as consequências futuras do desenvolvimento de infra-estruturas de transporte e apresentar sugestões para acções de desfragmentação.

Palavras-chave: Conectividade, Infra-estruturas lineares, Fragmentação, Montado, Mortalidade, *Strix aluco*.

1. Introduction

Habitat fragmentation is a major consequence of transportation infrastructure development, connecting the multi-urban spread as the application of central place theory, described by Walter Christaller (1972). Despite the increasing interest in road ecology, according to Jaeger (2002), our knowledge about the fragmentation effects of roads on wildlife populations is still limited, and has little predictive power. In recent years, to address this issue geo-information technologies have been increasingly used to answer the questions raised.

In a conservation scenario, the increasing landscape fragmentation caused by human infrastructures poses a serious threat to wildlife species by its negative impact on demography evolution. Connectivity between territories and suitable habitats are fundamental for dispersal, given the uncertainties related to the expected climatic changes in species demography (Sutherland *et al*., 2007). Herein, we present a case study of tawny owl (*Strix aluco*) casualties, where related to habitat fragmentation as a consequence of transport infrastructures usage.

2. State of the art

Transportation infrastructures, like roads, highways and railways, are known sources of habitat loss and fragmentation, pollution and mortality in animal populations (Bennet, 1991; Forman & Alexander, 1998; Trombulak & Frissel, 2000). Roads can affect animal populations in many ways like, killing (Loos & Kerlinger, 1993; Hels & Buchwald, 2001; Brito & Álvares, 2004; Petronilho & Dias, 2005; Grilo *et al*., 2009), behavior modifications, avoidance (Reijnen *et al*., 1996; Reijnen *et al*., 1997; Benítez-López *et al*., 2010), and population disruption caused by a barrier effect (Corlatti *et al*., 2009; Kerth & Melber, 2009). Roads might isolate metapopulations, increasing extinction risk and blocking recolonization (van der Zande *et al*., 1980; Mader, 1984; Reh & Seitz, 1990; Vos & Chardon, 1998; Forman *et al*., 2003; Kramer-Schadt *et al*., 2004).

Road traffic has been shown to have a negative effect on most terrestrial vertebrates. In general, birds are highly vulnerable to the effects of road traffic or more specifically, the density-depressing effect (Erritzoe *et al*., 2003; Fahrig & Rytwinski, 2009). The density-depressing effect on birds, is high in woodland areas crossed by roads (Reijnen & Foppen, 1994; Foppen & Reijnen, 1994; Reijnen *et al*., 1995), but it occurs as well in other forms of land use (Reijnen *et al*., 1996; Reijnen *et al*., 1997).

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Road casualties can represent a considerable source of non-natural mortality, in particular for owls (Hernandez, 1988; de Bruijn, 1994; Massemin & Zorn 1998; Ramsden, 2003). Owls predominantly show nocturnal activity, having developed behavioral adaptations to night conditions, but when exposed to car-lights they may face temporary blindness. Owls regularly use a variety of support structures distributed in roadsides, like trees, fences, electrical wires, and posts (Massemin *et al*., 1998; Ramsden, 2003) hence these foraging habits along road verges makes them more prone to road casualties.

Behavioral responses to road traffic include avoidance of traffic emissions and disturbance of noise, lights and chemicals (Jaeger *et al*., 2005). At the same time, owls can sometimes be attracted to roadsides, as areas of food abundance, due to the abundance of small mammals (Fajardo *et al*., 1992). The abundance of small mammals is positively correlated with the effects of roads, as a combination of other factors, like the high rates of casualties in their predators (Fahrig & Rytwinski, 2009).

Our hypothesis was as follows: tawny owl casualty hotspots occur at roads crossing habitats with structural connectivity. To verify this hypothesis we defined the following goals: (1) to identify the spatial pattern of points casualties of tawny owl vehicle collision; (2) to develop a spatial model of casualties (inference unsample roads areas); (3) to quantify the proportion of the tawny owl population that may be victim of road-killing; and, (4) to identify fragmented and disturbed areas.

3. Materials, data and methods

To accomplish our goals we: (a) collected data of population density and per capita traffic mortality of tawny owl (b) established a reference density distribution (interpolation of surveys) of this species by the use of kriging with external drift (c) identify the hotspots location (space and time casualties clusters) in point pattern analysis (continuous Poisson), and (d) used independent predictors to generate a spatial model of the probability and abundance of road mortality occurrence, using generalized linear models (GLMs).

The survey data was complemented by information generated and managed on a geo-information system (GIS). The general inputs of our GIS project were in vector format, like roads, point surveys, hydrographic lines or land cover polygons. In order to use the external drift and establish the species habitat model, we used the Corine land cover 2006 as the matrix of categorical classes. Corine land cover was reclassified as binary class with the aggregation of 2.4.4-Agro-forestry Areas, and 3.1.1-Broad-leaved Forest as the tawny owl habitat, against the all other existent classes (no-habitat).

Information was generated as a tessellation of the study area in hexagons, the allocation unit of each hexagon was 25 ha, representative of the species average home range. The hexagon geometric shape was chosen in order to maximize the area of representativeness. The general inputs were converted into grid surfaces and used to provide independent data attributes of each hexagon unit. The hexagon layer was used as spatial unit to extract the mean or dominant value of all data

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covers. We established a systematic matrix of independent variables for each hexagon unit and used this for spatial model generation. The spatial models were performed using ArcGIS 9.1 (ESRI, 2005) software and the hexagon layer was edited in Patch Analyst 4 extension (Elkie *et al*., 1999).

3.1. Case study

Our model species, the tawny owl (*Strix aluco*) belongs to the Order Strigiformes, having a least concern (LC) status according to the red list of threatened species of the International Union for Conservation of Nature (IUCN). It is a sedentary and territorial species that can occupy a territory from 7 to 75 ha (Cramp, 1985). However, more recently using telemetry, its average home range was estimated to be 27 ha of 80% kernel (Sunde & Bolstad, 2004).

Tawny owls show habitat preference for woodland areas, and in Portugal they use oak (*Quercus*) and pine (*Pinus*) woodlands, tree parks and riparian galleries (Lourenço *et al*., 2002; Equipa Atlas, 2008). This association has been found in former studies, which related the occurrence of tawny owl casualties where roads cross woodlands, and also with the presence of trees along the verges (Silva *et al*., 2008; Gomes *et al*., 2009). This species is relatively abundant, with considerable collections of available data, and may be an indicator of habitat quality.

3.1.1. Study area

The study area was confined by two focal urban areas, on the west by the village of Montemor-o-Novo, and, on the east, by the city of Évora (figure 1). The landscape morphology of the study area is characterized by a flat plain (100-300 m). The climate is typically Mediterranean, with hot dry summers (an average daily temperature of 35ºC in July), cool winters (averaging 5ºC in January), and 500-600 mm of rainfall between October-March, during which about 75% of annual rainfall occurs. The habitat land cover is a mosaic, dominated by holm oak *(Quercus rotundifolia)* and cork oak (*Quercus suber)* woodlands of variable tree cover density, frequently with a grassy area understory grazed by livestock (Pinto-Correia, 2000). The area is also marked by the dam of *Minutos*, scattered by vineyards and bordered by the Network Natura 2000 site of community importance of Monfurado hill.

The area is crossed by a Trans-European highway (A6) connecting Lisbon to Madrid, by national roads (EN 114 and EN4) connecting the local major cities, and also by the network of regional roads. To some extent, the roads are parallel among them, with less than 20 m between each other, making a considerable barrier or a "fence effect" for most animal movements (Jaeger & Fahrig, 2004). In the near future (2011), the area will be disturbed by the construction of the future Trans-European high-speed train, and a projected new regional road (IC 33).

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3.2. Surveys

A possible way to measure the spatial pattern of living distributions is the use of sampling points, which are easy to replicate in time and space (Pereira & Figueiredo, 2009). Point-referenced data are common in terrestrial ecology studies, identified in statistics by 'events'. Events refer to the position they occupy against any other arbitrary event in the study area. In this study the sampling unit was collected in point surveys, measuring the position and other attributes of the species occurrence and casualties.

The tawny owl census was conducted from March 2005 to May of 2007, and we used the playback of conspecific calls to detect its territories (Redpath, 1994; Zuberogoitia & Martínez, 2000). We visited 65 counting stations in 2005, replicating (65 + 2) stations in 2007. The counting stations were homogeneously distributed across the study area, and separated by at least 1.2 km. The census began at dusk and lasted the following 4 h, avoiding unfavorable weather conditions such as heavy rain or strong wind. Tawny owl calls were played over a 4-min period, after which we waited 10 min for replies. For each individual we registered age, sex, direction and distance. We plotted all information in GIS, and estimated the breeding pairs in each counting station. The rank was [0-4] breeding pairs per site (figure 2).

Road casualties were collected in 41 km sampling of two lane roads (EN4-EM370-EN114) between Évora and Montemor-o-Novo. Sampling was carried out over a 3-year period between December 2004 and December 2007, with a gap in 2005. The survey was done to collect all dead animals on the road almost every day, and we identified 135 tawny owl casualty positions from the original pool of collected data (figure 2). The dead carcasses sometimes provide additional information of individual status, i.e., sex, age, etc., but for the most part, recorded data just permitted us the position information and species identification. On average, each breeding pair produced three eggs, with just one, or, on occasion, two juveniles surviving to dispersion. It is documented that there is an increased number of casualties during the dispersion of juveniles (Erritzoe *et al*., 2003).

3.3. Point analysis and interpolation

Spatial point-pattern analysis aims to determine the spatial pattern through the individual distribution, and to establish a relationship with the underlying mechanisms of the observed pattern (Legendre, 1993). Usually, living distributions exhibit a non-random configuration based on the fact that values of samples that are close together tend to be more similar, considering a spatial autocorrelation or dependency relationship. A common way to identify the underlying mechanisms is by testing properties of a point-pattern against a simple random process (Goreaud & Pélissier, 2003). The patterns tend to be non-randomly located in space as we would expect from living individuals and communities as a sign of a regular modeling (Ebdon, 1985; Legendre, 1993). The points surveys of our study provide reference units (position), and were used to interpolate species density and define patterns of casualty hotspots.

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3.3.1. Density distribution (kriging interpolation)

An interpolation method was used, referred to as "Universal kriging" (Hengl *et al*., 2003). Kriging estimation is based on covariance structure of irregularly sampled points, assuming that covariance depends on the distance among points. When the features' values do not have a homogeneous behavior within a domain D, the assumption of stationarity of the mean is violated, and the ordinary kriging technique is not appropriated. Whenever there is a significant spatial trend in the data values, a universal kriging (UK) method may be more suitable (Hengl *et al*., 2003).

We used the resample of Corine landcover classes as the auxiliary variable of the interpolation; also known as kriging with external drift (KED) of the target value of interest (points of the sample birds' breeding pairs response). The relationship between bird species and cover trees (habitat patches) is well known as a strong statistical correlation. The sample and auxiliary variable was used to inference the target values at unsampled locations in a continuous grid surface. KED requires that both target and the external drift have a spatial structure that can be modeled, and have a spatially-dependent covariance. In order to improve our model, we reserved 10% of the datasets (points) for validation, and the interpolated surface was done in a SAGA software package (Hengl, 2007). The generated density surface was a fundamental input of independent variables in the subsequent GLM model input.

3.3.2. Space and time casualties clusters (continuous Poisson)

To identify local clustering in the spatial arrangement of tawny owl casualties, it was performed on the survey dataset a test of randomness with a continuous Poisson model. The method used to investigate the locations of mortality hotspots, hereafter referred as SaTScan, involved comparison of the spatial pattern of casualty occurrence with that expected in a random situation. The stochastic aspect of the data observations arose from random spatial locations. The SaTScan test of whether there is spatial auto-correlation or other divergences under the null hypothesis follows a homogeneous spatial Poisson process with constant intensity (Kulldorff, 1997). The outcome will reveal whether the casualties are clusters or randomly distributed in space.

The hotspots highlighted, were defined in a spatial window condition of a 314 m ratio-buffer, the ratio distance was defined to not overlap with more than the occurrence of two casualties and less 50% of all possible occurrences. The Monte-Carlo randomness confidence test was done to 9999 replications (P=0.001). The test was done for all surveyed points in two sets of temporal groups, for the dispersion season (April-September) and nesting season (October-March). The SaTScan method performs a pure spatial approach, and uses the precise (measure in Cartesian coordinates) locations where each fatality occurred. For these tests we used SaTScan v8.0.1 software (Kulldorff, 2009).

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3.4. Spatial model design

Our guideline of the model development was to look for variables with good explanatory power and a parsimonious meaning. The relationship between the independent predictors and the affected species causalities was modeled as follows: (a) reduction of predictors with the use of hierarchical cluster technique as exploratory analysis (figure 4); and, (b) a generalized linear model (GLM) to predict the probability and the number of casualties in each hexagon unit (McCullagh & Nelder, 1989).

We started with 20 pre-selected candidate models based on the criteria of: (i) biological significance; and, (ii) significant or near significant contribution of predictor variables to model improvement. The model selection was according to Akaike's Information Criterion (AIC) weights. The AIC weights sum to 1 for all candidate models. AIC weights can be interpreted as the likelihood of the best fitting model if we use another matrix of collected data again under identical circumstances (Burnham & Anderson, 2002). The statistics packages used for exploratory analysis and modeling developing were the SPSS 13.0 and S-Plus 2000 for Windows.

The spatial model was developed with 8 environmental predictors. From the initial pool of possible environmental predictor (n=26) matrix variables, a selection was made (based on exploratory analysis) of a sub-set of the most meaningful 8 (table 1). The sampling casualties of points (presence-absence and the occurrence number) were used as the dependent variable in n=90 training hexagons. A nested model of categorical and continuous data (interaction factors) was selected, from a group of 20 possible candidate models.

Nesting arises in models when the levels of one or more factors make sense only within the levels of other factors. In our case, the nesting factor was the, habitats (vs) no-habitat class with the species density. The models make possible to inference the mortality probability in the study area, more precise in the 358 hexagons that overlay with the existing or future roads and railway. The probability model was a logistic GLM of presence-absence mortality and a Poisson GLM occurrence of mortalities.

4. Results

In 2005, we detected 81 tawny owl territories in 49 counting stations with responses (75%), while in 2007, we detected 79 territories in 44 counting stations with responses (65%). The number of tawny owl breeding pairs detected per counting station varied between 0 and 4. Based on the discrete sampling, the generated density surface is a continuous space with values between 0 and 4 breeding pairs. The generated map shows the distribution pattern where there is a central core of high density, and the pattern is oriented in a NW-SE direction (figure 2).

Considering all point casualties (figure 3) in the dispersion and nesting survey, the occurrence is unbalanced during the year; in the breeding season the adults are further exposed, and in the dispersion season the large number of migrating juveniles are further exposed (figure 5). The results of SaTScan highlight a significant number of mortality hotspots. Considering both seasons in

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one analysis, 19 hotspot locations were identified with a (*P* =< 0.05), and a range of 2-11 observed casualties. Considering just the dispersion season (*P* =< 0.05), there are 17 hotspots with a range of 2–9 observed casualties. Considering just the nesting season (*P* =< 0.05), there are 6 hotspots with a range of 2-4 observed casualties (figure 6). The number of hotspots in each season is considerably different, but most differences are among the number of casualties in the hotspots. The mean of casualties in the dispersion season is 5 in each hotspot, and 3 in the nesting season. The radius of a general hotspot area is between 5 and 300 m. The crossings of natural corridor areas (e.g. water line vegetation) are usually very well defined hotspots (figure 7).

The selected spatial models were made by the two principal nested predictors (species density and the habitat land cover), complemented by the road distance, water line distance, and night traffic density. The results of the likelihood mortalities model validated the hotspot areas, and more than 50% of the hexagons have a high potential rate of mortality (figure 8). According to the model, we could identify 8 presently critical areas, and three future new areas of high impact (figure 9). The estimated population abundance was ~1080 individuals by year in the study area. The results from population dynamics show us that there are 271 breeding pairs, this corresponds to a density of 0.64 breeding pairs per km^2. The estimated mortality is about 145 individuals by year, which corresponds to a direct casualty rate of 13.5%, related to the existing infrastructures.

5. Discussion and conclusions

Our results show that tawny owl mortality hotspots occur mainly where roads cross high-quality habitats, where the density of population follows the habitat continuity. The spatial analysis in our study case revealed an evident pattern, in an empirical approach based on observational data. Nevertheless, it should be stated that the same type of pattern may result from different kinds of processes (Perry *et al*., 2002; Wiegand & Moloney, 2004). Conclusions should be conservative, and consider that the pattern may include other process components (i.e. telemetry data, eggs count), as assessed from different types of analyses and modeling approaches. However, the applied methods give us the confidence that the described methods herein are a useful approach to the exploratory stage of data explanation.

Using the KED was justified as the better way to interpolate our measured variable (e.g. number of breeding pairs), to fit a linear unbiased estimator of the sampling points. The use of auxiliary external drift (e.g. habitat cover) in relation to the samples, proved a good operating result. In our study we show that where there is a small sample set of the dependent variable, the external drift (co-located measurements) is useful to help the interpolation. The observed density is higher than in other Portuguese areas (Lourenço *et al*., 2002), but less than other countries studied (Sunde & Bolstad, 2004). The different density results may indicate that this species is sensitive to the local circumstances. The central core of the species distribution is the best preserved area with more demographic dynamics. The habitat area is split (fragmented) by high traffic roads at the NW by the national road EN04, and at the SE by highway A6. The area is also confined by the EM370 at the north, and by the conjugated effect of EN114 and highway A6 at the south, with a barrier effect near the SAC. Considering the existence of future infrastructures, the core density has been progressively isolated and this may affect the resilience of the species.

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The SaTScan method based on the continuous Poisson model of point intensity proved to be an option to other existing methods, like Malo's (Gomes *et al*., 2009). The tawny owl hotspot locations reveal an evident unbalanced relationship in the two seasons observed. Few casualties, but very spatially located in the nesting season; and a large number of casualties with a spatial spreading distribution in the dispersion season. The evidences of unbalance may be explained by the population dynamics in close relationship to the habitat distribution and fragmentation. As could be expected, the identified hotspot casualties were almost exclusively near habitat patches of high tree density. Significant spatial autocorrelation was identified in the distribution of casualties, meaning that the casualties occurred in clusters, rather than being randomly distributed along a road. The radius values of the hotspots define a considerable dispersion in dead areas, and their location (spatial identification) may help us on the prediction of future occurrences. The identification of locations of critical casualties can give us the opportunity to implement defragmentation management measures. One of the measures can be the installing of road signals to reduce traffic speed in the critical areas. Another complemented measure is forcing birds to fly higher whilst crossing, using the appropriate tree management in measures to promote montado connectivity.

The usage of a spatial model helped us to evidence (inference) the impact of the new developing infrastructures on species population. The predictive spatial model reveals that major factors of explanations of *Strix aluco* casualties occur at split montado habitat patches, or at focal tree locations in dense population areas. Nevertheless, in some circumstances it was observed that when infrastructures are between habitat and no-habitat the impacts are lower. The reasons for this could be related to the fact that species avoid crossing large areas of no-habitat. Tawny owl casualties are related to habitat fragmentation, showing factors addition, and interactions between road traffic and species population density. In the near future, the study area will be crossed by a line of a new high-speed train. We know that the species habitat will be affected, increasing new critical areas, even if the railway traffic is not directed compared to the road traffic type. The resultant maps of likelihood mortality occurrence confirm the hotspot areas, but most of all, show us the inference rates in the unsampled roads and railway.

As in other research of bird mortality, the focus tends to be on the deaths of first-year birds during juvenile dispersal (Ramsden, 2003). This bird species in adult stage do not normally move out of their home range. The surviving juveniles (to other causes of death, i.e. starvation) disperse from their parents' home range, mainly between July and October, but it should be said that in other latitudes, these months can be different. The core of the study area, where productivity exceeds mortality is a "source" area, and the juveniles disperse to the "sink", where the population level is balanced by birds coming from other areas. The core density area seems to be a "source" area. If we consider the future developments (railway and road) at mean road traffic scores, the mortalities will increase 3%, and increase to 16.5%. Compared to related studies as in county Devon in the United Kingdom, the estimated rate related to juveniles' dispersion is around 18% (Ramsden, 2003). This species mortality rate may be a good indirect indicator to use on other species of concern, like rare or endangered species. If we can define an association between species behavior and mortality, this can help us on future research.

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Usually the lack of data (eg. the size of populations) does not permit for the assessment of the true impact of fragmentation. Studies on the long-term effects of fragmentation, for a comprehensive assessment of general species population dynamics are required (Jaeger *et al*., 2007). The spatial models, as the one in development herein, can be a powerful approach to use when spatial data is scarce, and to predict impact factors. Spatial models are fast growing for use in ecology studies; their success is related to our needs of spatial explanation and prediction. The use of predictive models is probabilistic in nature, and the choice of the evaluation measure should be guided by the aims of the study. The spatial models may help to identify solutions and propose defragmentation actions, allowing for the mitigation measures of casualties to be determined.

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TABLES

Table 1. List of used environmental predictors

Name	Description	Source process
COO_X	Hexagon centroid coordinate X	Geometry
COO_Y	Hexagon centroid coordinate Y	Geometry
ROAD_DIS	Distance of hexagon centroid to proximity road	Proximity
HIDRO_DI	Distance of hexagon centroid to proximity water line	Proximity
DIST_GR	Distance of hexagon centroid to "some" proximity riparian habitat	Proximity
TRAFEGO_H	Road average of night traffic load per hour	Traffic statistics
MEAN_UK	Bird densities'	Kriging interpolation
SOLO_B	Corine land cover class (Habitat-No Habitat)	Reclass

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FIGURES

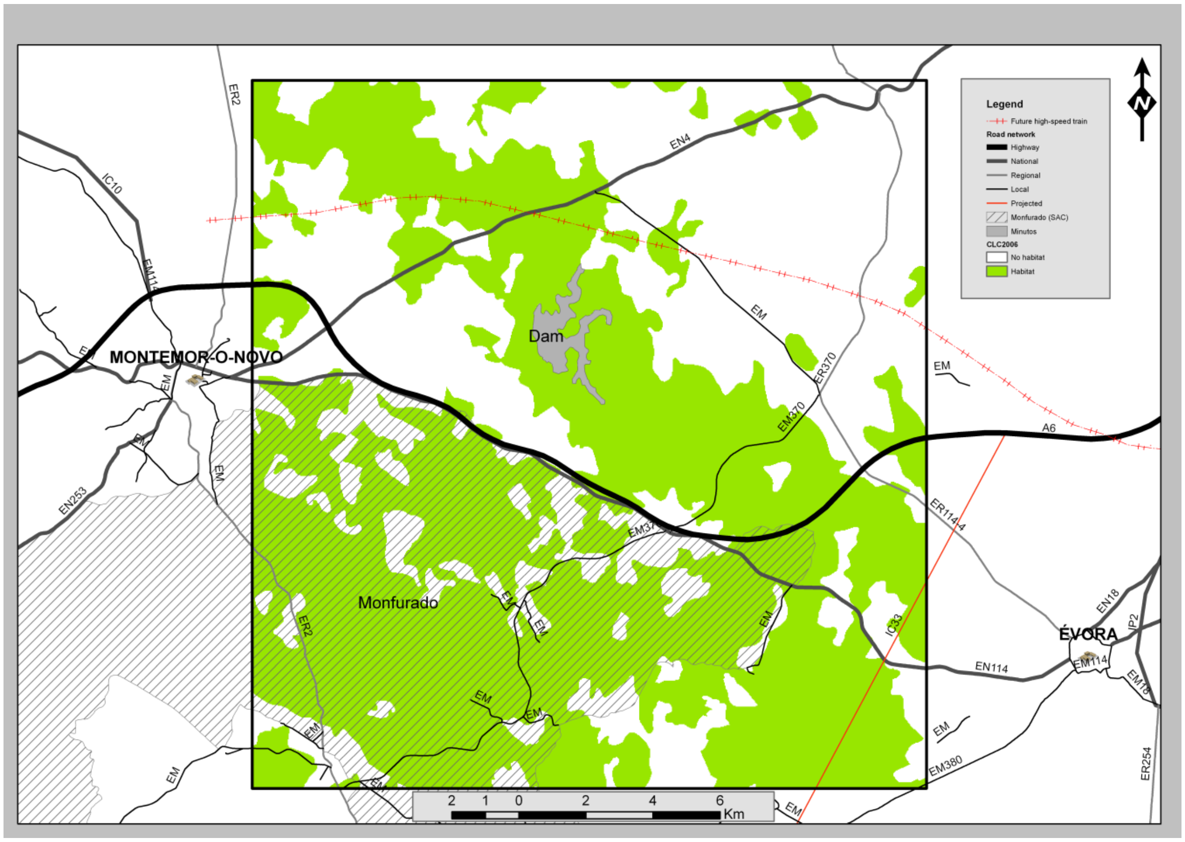

Figure 1. Study area with almost 42.500.ha spitted by the network of roads and future railway trans.

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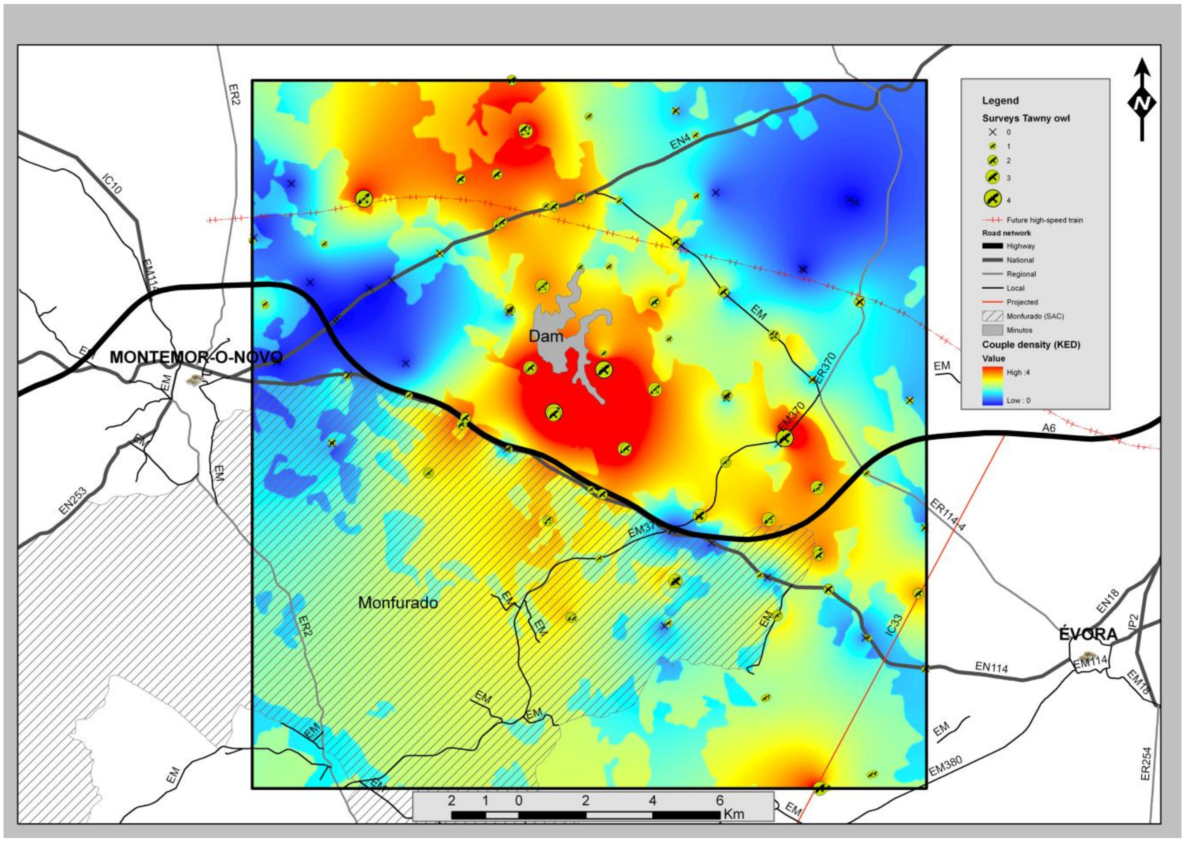

Figure 2. The 66 sampling survey sites of Tawny owl and the generated kriging with external drifts density surface. There is a central core of high density; the pattern is oriented in a NW-SE direction.

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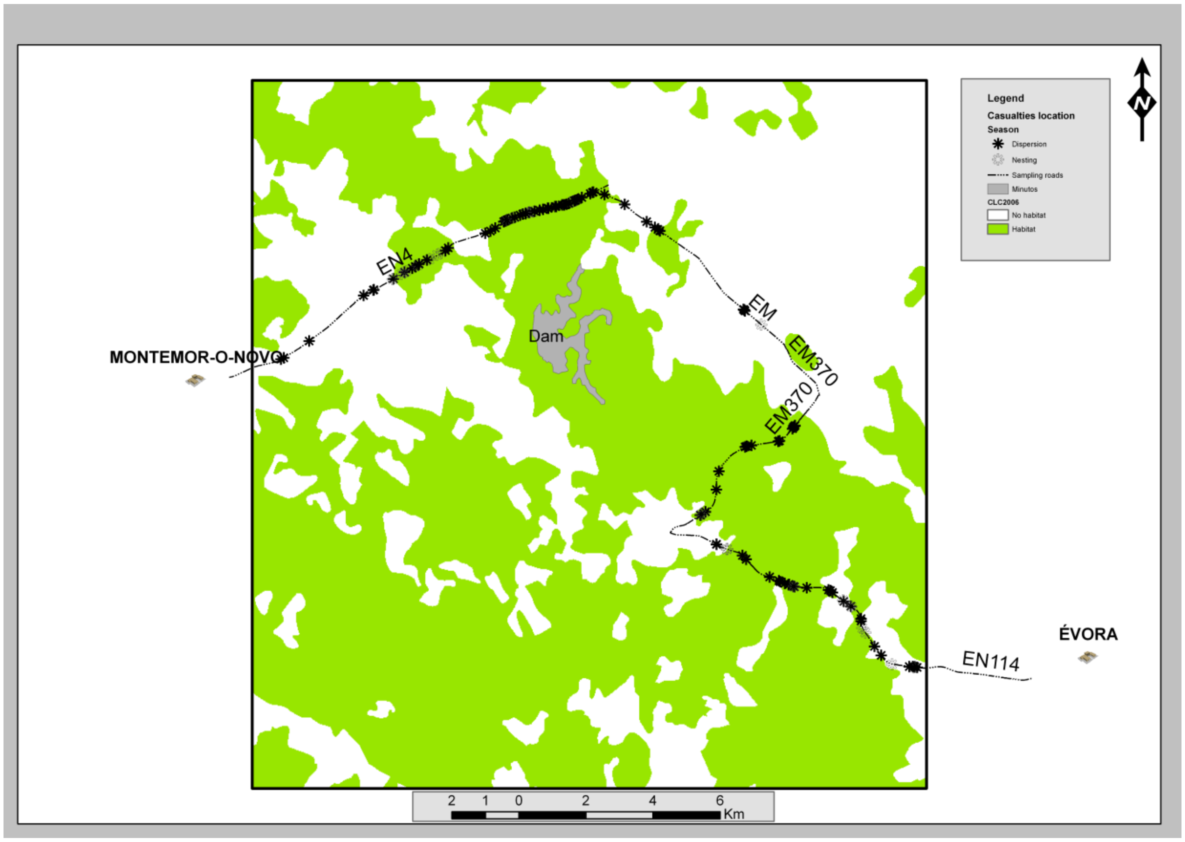

Figure 3. The 135 casualties' locations of Tawny owl, in the national road EN04 and EM370. The pattern reveals a close relation with the population density surface and by road split (barrier) areas of habitat shape.

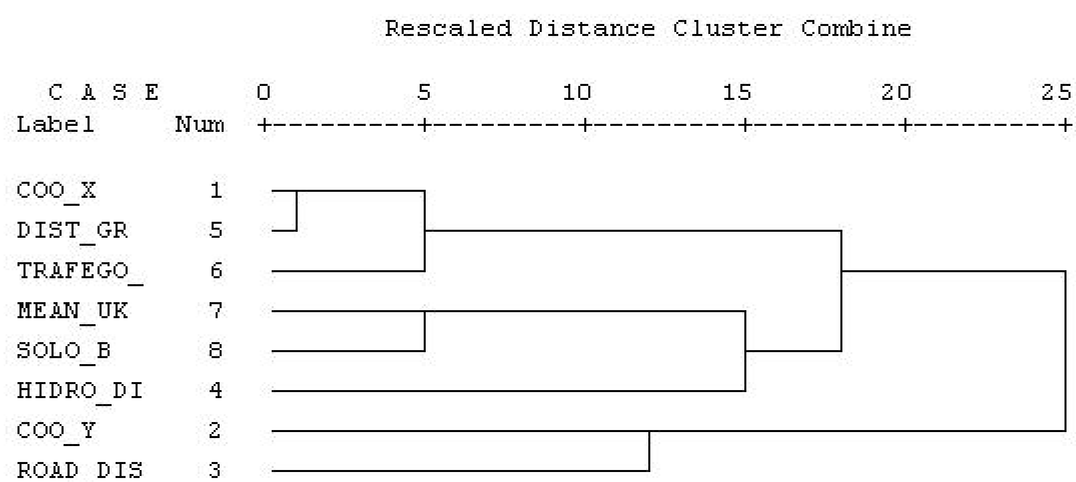

Figure 4. Dendrogram from the hierarchical cluster analysis, the land use (7) and density (8) are the most homogeneity environmental predictors.

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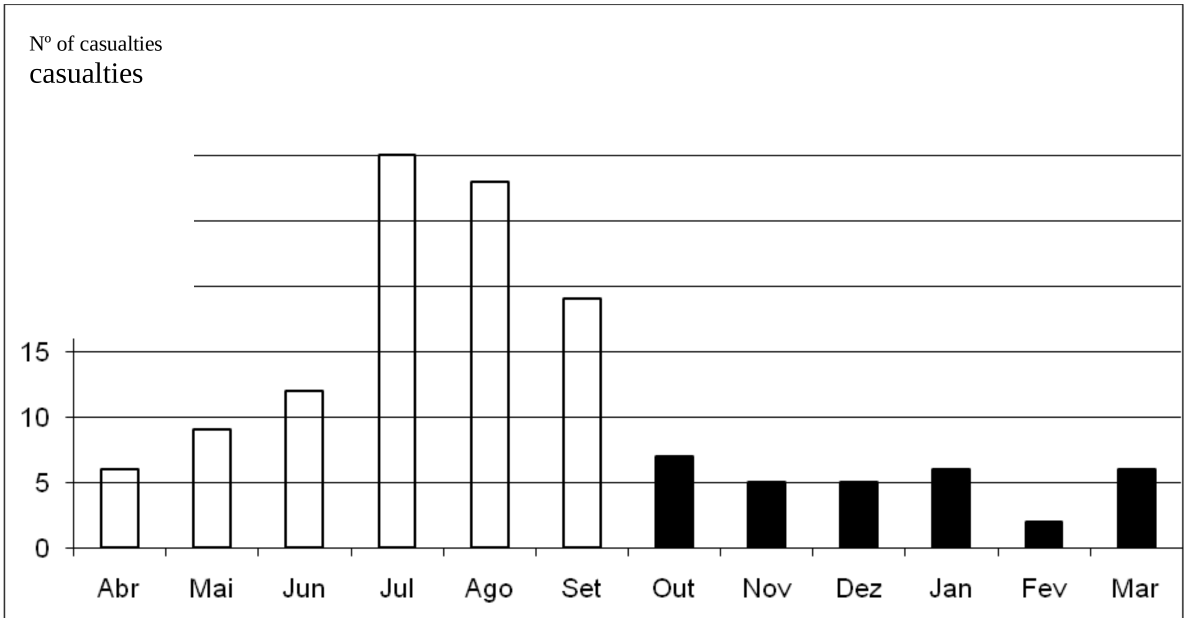

Figure 5. Seasonal dynamics of Tawny owl casualties' count in the survey time, line bars represent the migration and solid bars the nested season.

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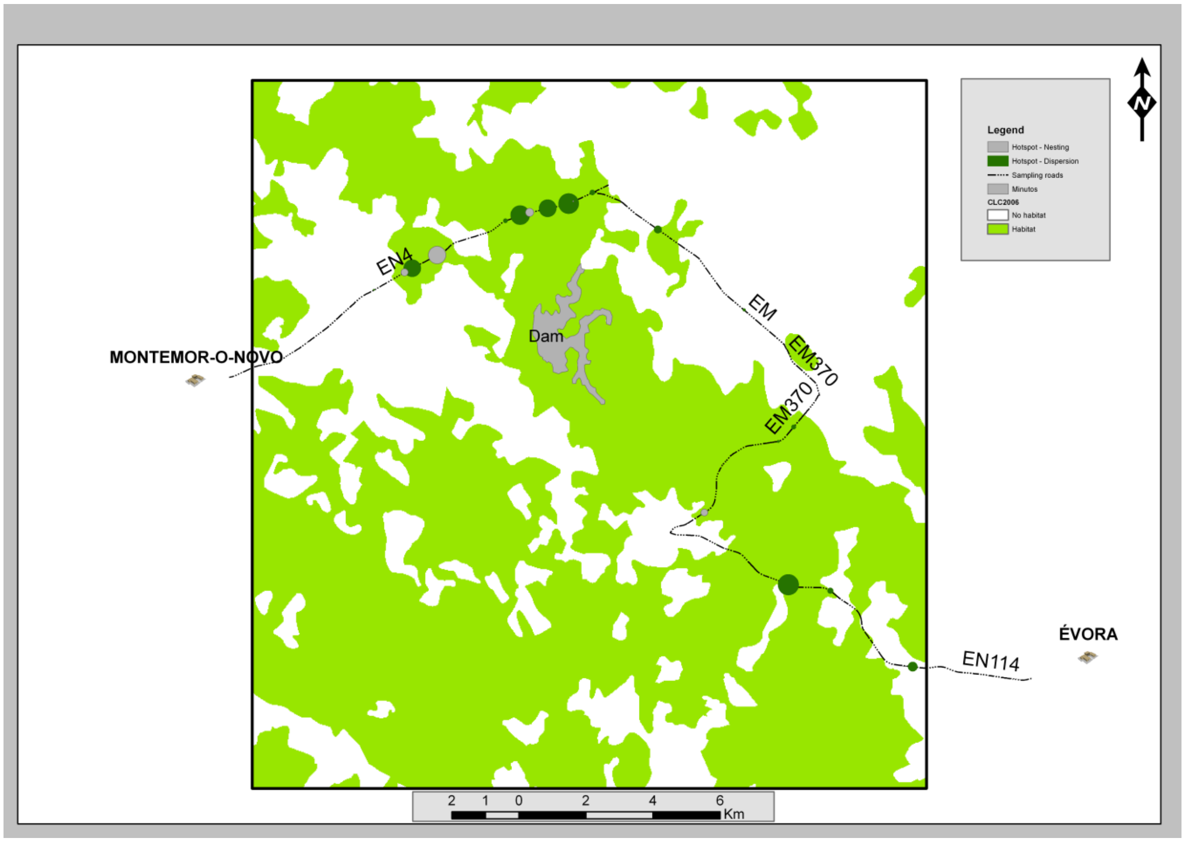

Figure 6. Mortality hotspots are tendency located on contiguity habitat patch.

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Figure 7. This is one of the well documented examples in study area of hotspot mortalities related to natural corridors (e.g. water line vegetation) cross by human made barriers.

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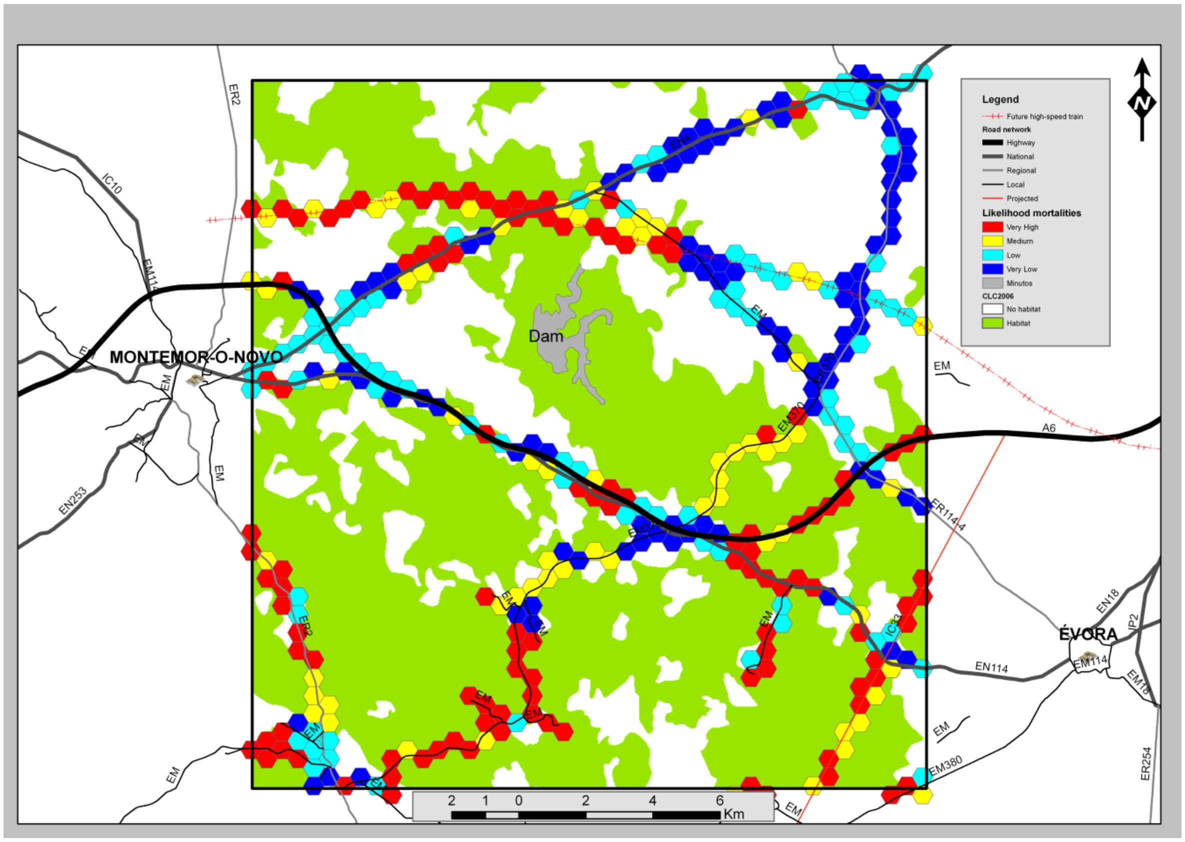

Figure 8. The generated spatial model of likelihood mortalities occurrences shows problematic areas of the impact of the existing and future infrastructures.

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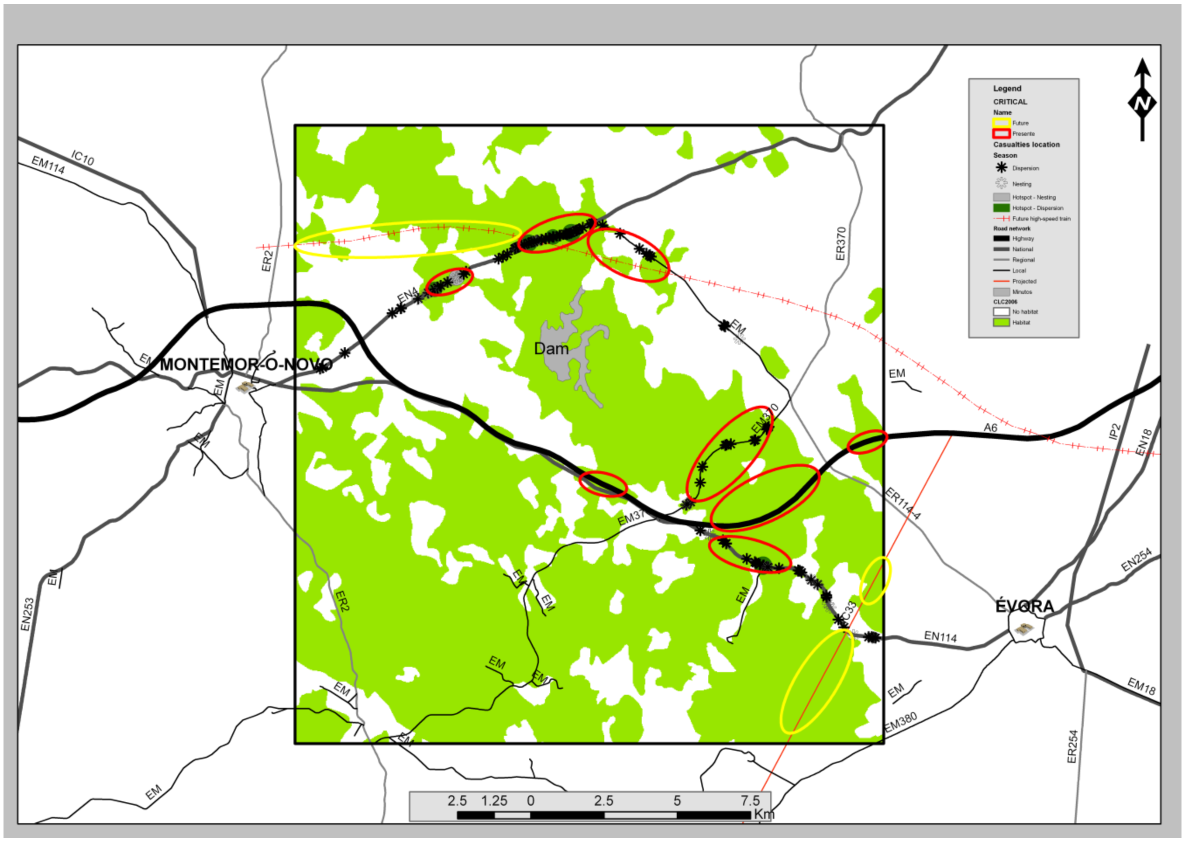

Figure 9. The present and the near future critical areas of infrastructures impact.

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