GEOGRAPHIC MODELING OF HABITATS FRAGMENTATION AND CONNECTIVITY: CASE STUDIES ON SPECIES LOCAL PATTERN DISTRIBUTION.

MODELAÇÃO GEOGRÁFICA DA FRAGMENTAÇÃO E CONECTIVIDADE DE HABITATS: CASOS DE ESTUDO NOS PADRÕES DE DISTRIBUIÇÃO LOCAL DE ESPÉCIES SELVAGENS.

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À Ana, Catarina e Raquel

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ABSTRACT

Habitat fragmentation and the resultant reduction in connectivity are process of major importance in the persistence and patterns distribution of wildlife species. This thesis focuses on habitat fragmentation and connectivity, assessing their consequences on the local patterns distribution of wildlife species. The cases studies were published and conducted with monitoring data systematized using a common database. The case studies were located in the Alentejo region between the years of 1995 and 2005. The case studies are supported by examples of local impacts of fragmentation on the habitat connectivity of birds and reptile species patterns distribution. The observed pattern-process interactions are assessing by geographic modeling techniques. Methodologies were developed based on the innovative application of spatial statistical and networks analysis. The results show that the geographic modeling represents an added value to the understanding pattern-process interactions. The findings show how much the local distribution patterns of individuals are affected by habitat disturbances.

RESUMO

A fragmentação dos habitats e a conectividade são processos de importância maior na persistência e nos padrões de distribuição das espécies selvagens. Esta tese centra-se na avaliação da fragmentação e conectividade dos habitats nos padrões locais de distribuição de espécies selvagens. Para tal foram realizados casos de estudo, com dados relativos a monitorizações efectuadas no Alentejo entre os anos de 1995 e 2005 e sistematizados numa base dados. Os casos de estudo foram publicados e são suportados por exemplos de impactes locais no padrão de distribuição de espécies de aves e réptil. Foram utilizadas técnicas de modelação geográfica na descrição e avaliação dos processos e padrões observados. Aplicadas e desenvolvidas metodologias inovadoras, com o suporte de técnicas de estatística espacial e análise de redes. Os resultados mostram que a modelação geográfica representa uma *mais-valia* para a compreensão da dinâmica entre *padrões-processos*. Os resultados revelam o quanto, os padrões de distribuição local dos indivíduos são afectados pelas alterações nos habitats.

OUTLINE

This PhD. thesis communicates a substantial part of my work on geographic modeling of habitat fragmentation and connectivity on the local pattern distributions of wildlife species. Case studies are presented, and the relationships between the habitat predictors and the response of the local species distribution pattern are modeled. The text of the thesis is structured by articles, published between 2007 and 2011. The text is outlined as follows:

Chapter 1 Introduction - Provides an introductory overview, based on a literature review, related to general research questions currently of interest;

Habitat fragmentation is a state of discontinuity that results from decrease in available habitat area and increase in the isolation of the remaining habitat patches. Habitat fragmentation may have effects on the connectivity and inherence of species' local pattern distributions. The relationships between landscape patterns and species' responses to those patterns (marked by life-history traits) directly relates to spatial processes. The analysis of pattern-process relationships includes (i) understanding the interactions between abiotic and biotic landscape elements, (ii) identifying the driving forces and underlying mechanisms, and (iii) detecting valid predictions.

Identifying relationships between patterns and processes contributes to enhancing multi-dimensional insights on biodiversity conservation and sustainable planning. If one considers that patterns are related to processes, then some landscape metrics can be used to assess habitats and species' patterns. The uses of landscape metrics helps to measure the ecological response by assessing prediction strength with statistical methods. Network analysis, in association with percolation theory, has been a useful approach to model the ecological thresholds of connectivity and distance.

Chapter 2 Biogeographic Data Modeling – Provides a database link to a mapping application, as a data tool to support Species Distribution Modeling (SDMs);

Collecting records does not always signify access to the information. There are many reasons for this; most are related to organization, management (e.g. lost files) and quality issues (e.g. corrupt files). Quality is an essential aspect of information competitiveness. Organized data enable better understanding of species and habitat pattern distributions. Legislative frameworks and environmental health indicators demand high quality information of species' locations and natural resources. Research institutions and nongovernmental organizations (NGOs) accumulate substantial species records from fieldwork or bibliographic catalogs. Nevertheless, strategic information is can be difficult to find; therefore, efficient data management is essential to identify relevant information in the decision making process.

Recording biological species involves different aspects and computer science issues, such as scale collecting, temporality, heterogeneity and validity. In recent years, biological data have emerged from both print and digital sources, providing thousands of non-structured records. The registration of species allows us to assess and to quantify biodiversity at different scales (space-time). Long-term data series of species communities and populations may improve the decisions of present trends and the definition of policies. The developments of informatics tools are essential for exploring biogeographic data.

Chapter 3 Large Areas Transformation - Presents the time-series monitoring of steppe birds, considering the habitat fragmentation related to the Alqueva reservoir, by assessing the effects of ecological processes on distribution pattern;

This study describes a test for measuring the effects of the flooding reservoir on Steppe bird distribution. Based on spatial point-pattern analysis, the text demonstrates the relevance of spatial point-pattern analysis to bird surveys and shows how spatial data and geographic modeling can be useful for identifying habitat fragmentation consequences of reservoir disturbances. The results show that the adopted methods provide useful statistics for local data monitoring. The methods help us to measure and quantify the effects of habitat fragmentation from the reservoir in the species pattern and density reshape. Natural and human disturbances can reshape communities and species distributions, such as in the case of dam construction; the consequences of a disturbance can therefore be tested and measured using sample data and spatial pattern analysis.

The spatial structure of an ecosystem plays a key role in its dynamics, and spatial disturbance may result in different future evolution patterns. Spatial pattern analysis is descriptive, based on assumptions and constraints, and its use characterizes distributions to help us formulate further hypotheses. The spatial pattern of species distribution is related to different ecological processes. Understanding ecological processes starts with identifying spatial patterns, spatial forces, and dynamic interactions. Spatial pattern discovery allows testing of different underlying ecological processes and changes in recognizable structures. The patterns of species distributions tend to be non-randomly located in space (as a sign of a regular modeling), as we expect from live individuals and communities. Usually, living distributions exhibit a non-random configuration considering a spatial autocorrelation or dependency relationship.

Chapter 4 Linear Infrastructures Impacts - This case study assesses the tawny owl habitat fragmentation, as a result of a road network or future scenarios, in relation to species density and hotspots of road casualties;

This study models the tawny owl population survey in relation to habitat fragmentation. The results show that tawny owl mortality hotspots occur mainly where roads cross high-quality habitats, where the density of population follows the habitat continuity network. Using an empirical approach based on the observational data, spatial analysis reveals a clear pattern. Nevertheless, the same type of pattern might result from different kinds of processes. Thus, the pattern may include other process components (i.e. telemetry data, egg count) as assessed from different types of analyses and modeling approaches.

Habitat fragmentation is a major consequence of transportation infrastructure development, connecting the multi-urban spread with the application of central place theory (Christaller, 1972). Despite gaining interest in road ecology, knowledge about the fragmentation effects of roads on wildlife populations is still limited. In recent years, geo-information technologies have been increasingly used to answer the questions raised. In a conservation scenario, landscape fragmentation caused by human infrastructures poses a serious threat to wildlife species through its negative impact on demography. Connectivity between territories and suitable habitats are fundamental for dispersal, given the uncertainties related to the expected climatic changes in species' demography.

Chapter 5 Connections in Scarce Habitat - A pattern-process case study is presented, using fresh water turtles (European pond turtle) as model species of a metapopulation in scarce habitat patches connected in a network of threshold distance function;

This study involves an innovative modeling of habitat connectivity of European pond turtles. The modeling methods are based on a hybrid approach combining SDMs with network analysis. The results illustrate the potential of graph-based network analysis to assist landscape management and conservation planning of populations occupying small-scattered habitat patches within a non-habitat matrix. The connectivity-based attribute values successfully identified the pond systems occupied by the European pond turtle as well as indicators of those ponds showing good population status, according to age structure.

One way to assess the structure and the behavior of a spatial complex system is to identify its properties on a graph model. This approach is especially useful to address questions related to network structure, object centrality, their interactions and flow efficiency. A graph provides a simple method of representing habitat patches within a landscape matrix. Habitat patches are defined by a set of nodes connected by links, each with its own attribute value. A network may contain several subnets or components, defined as a set of linked nodes for a given threshold distance associated to dispersal process. One important feature of networks is the existence of cut-nodes, whose removal would disconnect one component into two or more subcomponents. Another important feature is the existence of a maximal complete subgraph (clique), defined by the node subset such that every two nodes are connected by a link. These and many other relevant network properties can be computed using graph models, making them potentially useful tools in conservation planning.

Chapter 6 Synthesis - Provides a general discussion of the work performed and future perspectives;

The work involves the study of the relationship of habitat fragmentation and connectivity in the local pattern distribution of wild species. The case studies are peer-review published articles in the context of geographic modeling approaches that contribute to the understating and prediction of some aspects of pattern-process interaction. In the case studies, strategies to gain insights were governed by process description, pattern detection as well as simulation and generation scenarios. They were assessed based on four intraspecific population processes: Distribution, reproduction, mortality and dispersion. The methodologies may contribute to some level of spatial transference. Some case studies achieved results that may translate into spatial standards and thus to management and conservation planning.

Mobility and home range are important for understanding the effects of habitat fragmentation on species' population dynamics and distribution. In practice, not all species exhibit the same behavior to fragmentation, differing in terms of sensitivity. Interconnections of habitats are insurance to all species and largely represent a challenge for planning. Species respond differently to the fragmentation process with implications on other species patterns. It is expected that interpretation and the conceptual meaning of space may differ between species and, particularly, in relation to human perception. Fragmentation should be assessed by the species' perspective, since the same process can have different meanings and impacts.

DECLARATION

I declare that most of the work presented in this thesis is my own. The working study cases were developing as standalone articles published on peer review journals.

Chapter 1 and 6 is based on published article: **Pereira, M.,** Neves, N. & Figueiredo, D., 2007. Considerações sobre a fragmentação territorial e as redes de corredores ecológicos. *Revista de Geografia de Londrina*, 16(2): 5-24. http://www.uel.br/revistas/uel/index.php/geografia/issue/view/310

Chapter 2 is based on published article: **Pereira, M.,** 2007. Biological and geographical application tool. *Revista Forum Geográfico*, 2: 38-46. http://www.igeo.pt/servicos/CDI/biblioteca/publicacoesIGP/Revista_ForumGeografico.htm

Chapter 3 is the published article: **Pereira, M**. & Figueiredo, D., 2009. Effects of the Alqueva dam reservoir on the distribution of Steppe Birds. *Physical Geography*, 30(1): 43-63, doi: 10.2747/0272-3646.30.1.43

Chapter 4 is the published article: **Pereira, M**., Lourenço, R. & Mira, A., 2011. The role of habitat connectivity on road mortality of Tawny owls, *International Review of Geographical Information Science and Technology*, 11: 70-90. I wrote most of the text and perform geographic modeling and analyses, but Rui Lourenço, as the co-author, also contributed to the writing.

Chapter 5 is the published article: **Pereira, M**., Segurado, P. & Neves, N., 2011. Using spatial network structure in landscape management and planning: a case study with pond turtles. *Landscape and Urban Planning,* 100: 67-76, doi: 10.1016/j.landurbplan.2010.11.009. I wrote most of the text and perform most of geographic modeling and analyses, but Pedro Segurado, as the co-author, also contributed to the writing and the analyses.

1 INTRODUCTION

"*The issue of landscape fragmentation includes ecological processes, perceptions of the effects by society, economic land-use interests, and ethical principles.*" J. Jaeger (2002)

1.1 The Concepts

There is a global trend to simplify the matrix of habitats that are a result of human activities and actions in a space (O'Neill et al., 1997; McGarigal & Cushman, 2002). The human activities and actions in the space are key drivers for modeling landscape patterns (Riitters et al., 2002). The simplifications of habitats jeopardize directly, and affect territorial heterogeneity and biodiversity (Collinge, 1996; Tilman, 2000). Some human actions on a territory cause habitat fragmentation, with implications in landscape and pattern distribution of wild life species.

Patterns are the result of complex relationships between multiple factors, emerging from the abiotic template that controls gradient of biogeographic distribution and modeling the biotic interactions (Turner, 2005). The observed patterns are related more with the past than with the present (Vos et al., 2001; Turner, 2005). The important goal is to identify the factors and the scales that best explain variations local distribution patterns of the species.

Depending on its specific focus, the meaning of "pattern" and the meaning of "process" differ. Nevertheless, we consider pattern as an observation that is structured and significantly different from an emergent random process (Grimm et al., 2005; Schröoder & Seppelt, 2006). Patterns have spatial-temporal dimension, or fingerprints, and usually have forms of metainformation of the processes, from which they result. The spatial dimension can, for instance, be revealed in the distribution of individuals, species or ecological variables.

Process is defined as the interactions of different agents in an environment. The interactions among and within species populations create spatial patterns in organism's distributions (Jones et al. 1997 in: Turner, 2005). This is the case for the competition and predator-prey dynamics that may shape and produce spatial patterns living actors. Processes can be classified by the source, as exogenous, such as climate or fire actions and as endogenous, species demography or interactions (Bolliger et al., 2005).

Usually, the pattern-process analysis assesses the effect of pattern on the process. Inferring process from pattern is a difficult task, as space and time are a stage of variation processes in a mesh of processes intermingled spatial patterns (Fortin & Dale, 2005; Wagner & Fortin, 2005). The analyses of pattern–process interactions can be based on different approaches: (a) pattern description and landscape analysis, and (b) process description and landscape modeling (Schröoder & Seppelt, 2006). These issues are described in detail in later chapters.

Habitat fragmentation, in essence, is a simple and intuitive concept; it is a state of discontinuity as a result of landscape process (André, 1994; Forman, 1995; Franklin et al., 2002). Habitat fragmentation is a consequence of discontinuity, through a process of isolation in fragments of previously continuous habitats. It also includes destruction from splitting the habitat into small pieces (André, 1994; Forman, 1995). These types of habitat fragmentation are a result of the spatial mechanisms. This is a general definition, which may accommodate the different theoretical perspectives. However, for some authors, it is unclear concept, with several possible interpretations, in which the conceptual soundness is far from being firmly established (Fischer & Lindenmayer, 2006). In practice there is no single definition, rather there are situational views, which apply to specific case studies.

Habitat fragmentation has at least two associated factors: decrease in available habitat area and increase of the isolation of the remaining habitat patches (Hanski & Gilpin, 1991). A patch is a homogenous area at a particular scale, related to adjacent areas (patches) in spatial transition, with different gradients, intensity and quality. This definition can represent the generic concept of a habitat; defined as areas of resources needed by one or more species (Rutledge, 2003). Patch defining criteria may be arbitrary, related to how much variation is acceptable; the components that are ecologically relevant to the process of interest (i.e. species occurrence) and the minimum size of patches to be identified (mapped).

Habitat fragmentation results in considerable losses of coherence and continuity (Opdam & Wiens, 2002). The negative consequences of habitat fragmentation are materialized in abiotic and biotic components. Habitat fragmentation has negative consequences on the spatial connectivity, with changes of ecological processes and species patterns (Collinge, 1996; Serrano Sanz, 2002; Moilanen & Hanski, 2001; Fahrig, 2003). The associated factors may increase the fragmentation process (i.e. desertification and soil erosion). Some of the changes occurred in land use can become enhanced by recent factors such as climate change (Pearson & Dawson, 2005). It is expected emergent disturbance of local species patterns distribution as consequence of climate change process (Araújo & Thuiller, 2006).

Habitat fragmentation is a result of several mechanisms, but the human action is the most influential. The transformations induced by human actions on the globe are materialized in diverse forms; the extraction of resources is particularly relevant, such primary energy exploitation, as well as the increasing changes in agro-forestry activities. However, the extent of urbanization and the economic value of urban settlement are markedly contributed to the fragmentation of natural and semi-natural areas (Marulli & Mallarach, 2005). The changes in the matrix and space occupation are a reflection of urban development and increasing number of roads and facilities networks. According to Byron and Thompson (2000) road infrastructure is the main source of disturbance of natural territory in industrialized countries.

According to Forman (2000) road infrastructure affects one to two percent of the territory of the industrialized countries. The ground infrastructures for communication and transportation are among the most influential to habitat fragmentation (Heilman et al., 2002). Infrastructures may result in barriers to individuals and wild species communities' mobility, leading individuals and species to stochastic processes (Geneletti, 2004; Fraser & Stutchbury, 2004). It also induces indirect effects, such as rapid changes in species composition. Some of the effects are the reduction of genetic diversity by inbreeding depression, reflected in the rates of reproduction and immunity (Serrano & Sanz, 2002).

It is unclear which mechanisms contribute for species dispersal and breeding spaces. Does easy movement of species guarantees the preservation of biodiversity? The issues involved render a simple answer are difficult to achieve; and it is not the intention to fully respond to such questions here, but only to discuss the issue. The incorrect promotion of spatial connectivity may have the perverse effect of confining territorial individuals and made them easy preys. It may also have comparative disadvantages in process, such as fire, the spread of disease and competition with domestic species. We can theoretically consider that more fragmented habitats may have a positive role of filtering, acting as a barrier to the progression of "undesirable" individuals. Furthermore, connectivity can cause synchronized population dynamics, which can lead to increased risk of extinction for well-connected population.

According to Wiens (2002, Figure 1-1), the relationships between landscape patterns and the species responses to that pattern (marked by the species' life-history traits) are direct related to the spatially processes. The analysis of pattern-process relationships at a most high level of ecological analysis aims to (i) understand the interactions between abiotic and biotic landscape elements (ii) identify the driving forces and underlying mechanisms, and (iii) detect valid predictions (Schröoder & Seppelt, 2006).

The identification of relations between distribution patterns-process and the ecological functions, contribute to the improvement of multi-dimensional insights to biodiversity conservation and sustainable planning (Botequilha & Ahern, 2002; Bergon & Townsend, 2006). According to Herrmann and Dabbert (2003), promoting the spatial connectivity for conservation should occur at the regional level. According to these authors the regional level appears ideal, because it maximizes the resources expended and the benefits obtained. The national level is too costly and their implementation at the local level has no justifiable ecological benefit.

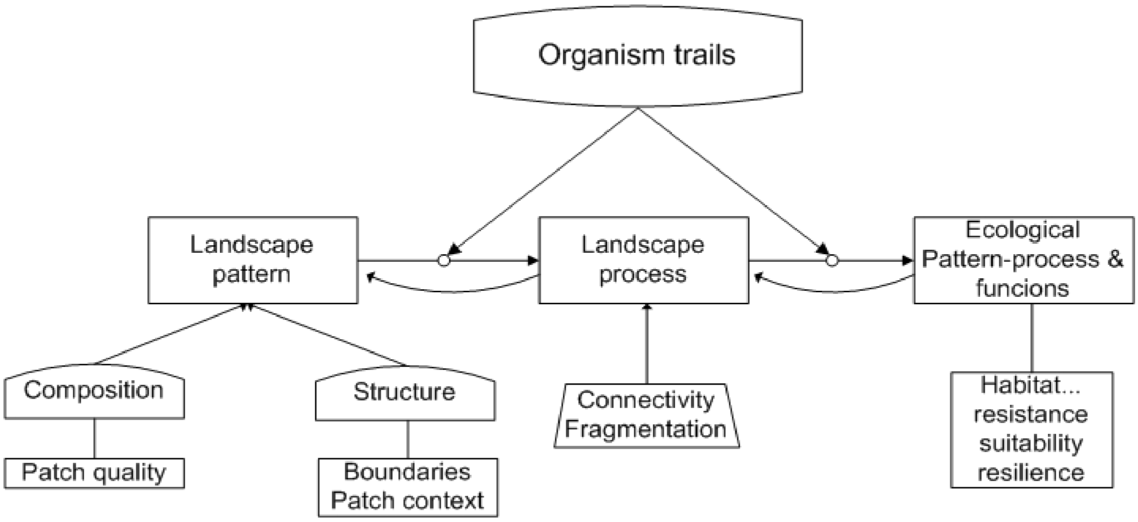

Figure 1-1. The framework connecting landscape patterns-processes of species traits (modified from Wiens, 2002; Schröoder & Seppelt, 2006).

Metapopulation is a useful approach to justify conservation planning at regional level (Vos et al., 2001). It elucidates the dynamics of a population's spread across the heterogeneous of spatial network patches connected to one another by a dispersal process (Hanski & Gilpin 1991; Hanski 1999). The premises are (i) extinctions occur regularly and are influenced by spatial attributes, but the probability decreases with patch size, (ii) sink patches are repopulated and the process is marked by habitat configuration, and (iii) habitat network should be connected to individuals dispersing successful (Lindenmayer, et al., 1999; Vos et al., 2001; Rozenfeld et al., 2008). This former approach directly links to "real-world" concerns over species persistence and diffusion, where connectivity is a key factor. We may consider other possible approaches, like the continuous gradient that is polarized by a center of geographical fragmentation as opposed to structural fragmentation (Franklin et al., 2002).

Habitat fragmentation contributes for the reduction of the local carrying capacity (effective patch area), with consequences on local extinction and colonization rates (Hanski, 2008). Metapopulation ecology provides a possible theoretical framework to incorporate the fragmentation pattern-process analysis in planning (Levins, 1970 in Hanski & Gilpin, 1991; Moilanen & Hanski, 2001). Metapopulation is based on the premises that spatially structured populations may face local extinction, but species resilience occurs at a regional scale, if local extinctions are compensated by external migrations. Populations of species occur as nodes in networks, and local populations in metapopulations structure inhabiting fragmented habitats (Hanski, 2008; Rozenfeld et al., 2008). Patterns are considered, *as part of* process, as in the case of recolonization successions that is inversely proportional to distance from source to sink areas.

The background information and concepts are related to *heterogeneity*: that refers to the complexity and variability of a property in time and space. Spatial heterogeneity is usually considered synonymous to *spatial pattern*. A *property* is any quantified entity, such as the configuration of a landscape matrix. Recent studies have evaluated the effects of habitat fragmentation of human actions on species persistence. The questions that aroused through these studies are based on the implications of fragmented habitat in the populations' persistence, composition and other ecological processes. The analysis focuses on spatial parameters, such as connectivity, shape, context, the edge effect and habitat heterogeneity (Collinge, 1996; Fahrig, 2002). Results indicate a close relationship between the fragmentation and distribution patterns of species and communities.

The majority of studies address the relationship of single specie with the habitat, with few examples where different groups or communities of species are evaluated simultaneously. The literature review carried out here refers the two groups of applied studies on the effects of habitat fragmentation in:

a) Land-use changes, with particular focus on the infrastructure of transportation and communication (Serrano & Sanz, 2002; Geneletti, 2004; von Raumer & Jaeger, 2007);
b) The demographic dynamics of species (Cushman & McGarigal, 2003, Fraser & Stutchbury, 2004).

As a matter of easiness and organization in the approach; the parameters used to assess the implications and the degree of habitat fragmentation are usually addressed individually. Nevertheless, their practical effects should be considered broadly and holistically. The factors of fragmentation are not new in Earth history; the question arises from the speed and the consequences of human activities. The fragmentation was derived from modern industrialism, which drastically changed the structure of natural habitats.

To assess the characterization of landscape dynamics has been proposed the use of indicators, supported by spatial metrics. At the EU level there has been a focus on landscape agri-environmental indicators; the Agricultural Council requested in July 1999 a report from the Commission. The report also included a pilot study that tested a fragmentation metric, which expresses connectivity and fragmentation of sensitive areas with the interest for nature conservation. The results highlight that the Atlantic bio-geographic region has the strongest anthropogenic fragmentation of the semi-natural areas. Lower fragmentation is observed in mountainous areas, usually associated to large areas that host animals (e.g. wolf) that need vast undisturbed areas (Steenmans & Pinborg, 2000). The explanations of the induced effects of habitat fragmentation outcomes for local pattern distributions are far from being fully understood and modeled.

At this point it’s important to address the following question: How can geographical modeling help us with spatial analysis and assessment of habitat fragmentation on local species pattern distribution?

1.2 Spatial assessment and technical underpinnings

If we consider that pattern is related to process, we may expect to use some landscape metrics to assess and evaluate habitat changes (Tischendorf, 2001). Different disciplines proposed sophisticated methods for pattern description and quantification. To understand the interplay of landscape patterns and ecological processes it is common to describe and quantify the spatial and temporal patterns by the use of metrics. Usually, landscape metrics come from land cover maps, and subsequently related with a measured ecological response by statistical methods to assess their prediction strength. The structure of landscape can be evaluated through a set of metrics, in two possible categories non-spatial and spatial (Gustafson, 1998). Non-spatial metrics assess composition attributes and spatial metrics assess the configuration attributes. According McGarigal et al. (2002), landscape metrics allow us to assess and describe the composition or occurrence of patches (Table 1-1), and also the physical and positional configuration of patches (Table 1-2). The use of metrics allows us to sort, homogeneity or heterogeneity of the patch elements of spatial matrix. Spatial heterogeneity quantification is essential to relate process to patterns (Turner 1989; Bergon et al., 2006).

In the XX century we have seen a significant development of metrics to quantify spatial structure and habitat fragmentation (Tischendorf, 2001). The advent of Geographic Information Systems (GIS) has facilitated the development and the application of metrics that characterize the space on different perspectives (McGarigal & Marks, 1995). According to Rutledge (2003), landscape metrics can be group into three time-series: proliferation, re-evaluation, and redirection. The development of landscape metrics reached a time of great maturity, with the widespread use of specific tools, but with some pointed ambiguities. Nevertheless, it is important to remind Turner (2005) "*spatial pattern analysis is a tool rather than a goal of its own*".

The critics to these metrics are mostly related to the high degree of correlation among them, sensitivity to changes in spatial scale (grain and extent), and diffuse response for different conditions. There are about 55 to 60 available metrics, with different levels of correlation or collinearity between them (Rutledge, 2003). The metrics are mostly descriptors and not all have the same applicability in the evaluation of habitat fragmentation (Rutledge, 2003; Li & Wu, 2004). That makes metrics selection a matter of particular importance. The use of landscape metrics should be guided by adequate criteria for phenomena under study, and the statistics behavior well understood (Li & Wu, 2004; Turner, 2005).

According to the review by McGarigal & Cushman (2002) on published fragmentation studies, they concluded that the effects of habitat fragmentation on species patterns distribution were poorly understood. They also concluded that composition has privileged importance over configuration. But it seems that habitat configuration assumes importance in landscapes of low and scarce habitat abundance, to poorly dispersed species in which dispersal mortality becomes critical. In the next section we review some cases of landscape metrics based on its usefulness and application on habitat fragmentation.

1.2.1 Composition metrics

The characteristics of habitat fragmentation can be described using composition metrics. The composition metrics assess the number of patches (e.g., diversity of patch types) and the area occupied by each patch of habitat. These metrics are used to quantify fragmentation. Nevertheless, they represent an incomplete frame, because the fragmentation concept includes the relative importance of each patch. These metrics are mostly statistic measuring, and may not have an ecological meaning. The average patch carrying capacity (effective patch areas) may represent a forward step, by adjusting the patch area to the individual species requirements (Vos et al., 2001).

Table 1-1. Example of some of available composition metrics

<table>
<tr><th>Name</th><th>Symbol</th><th>Description</th></tr>
<tr><td>Number of Patches</td><td>NP</td><td>Number of patches of a habitat category</td></tr>
<tr><td>Mean patch size</td><td>MPS</td><td>Average area of patches of a habitat category (unit: ha).</td></tr>
<tr><td>Patch density</td><td>PD</td><td>Density of patches in a category of habitat per unit area, e.g., per km^2</td></tr>
<tr><td>Average patch carrying capacity</td><td rowspan="2">Kavg</td><td>Combines the average patch size, and the species-specific individual area requirement</td></tr>
<tr><td>Average patch connectivity'</td><td>Combines both species and landscape characteristics.</td></tr>
</table>

The composition metrics are strongly correlated with the size occupied by each habitat patch. The size of habitat is especially important in the defense and preservation of biodiversity associated with it and in general, bigger is better. The size is related to the core area dimension, that is one of most applied metric, by is ecological meaning related to habitat use (McGarigal & Marks, 1995). The effects of habitat fragmentation are to some extent also related to matrix composition of surrounding non-habitat patches.

The studies confirm the strong relationship between the size of habitat patches and the persistence of the species that inhabit it. According to Vos et al., (2001) species with the largest individual area requirements and shortest dispersal distances are the most sensitive to fragmentation (Fahrig, 2003; Whittaker & Watson, 2005). Local extinctions may be a direct consequence of habitat patch reduction, or an indirect consequence, as a result of new inter-relationships not supported by species.

Studies with the bird *Piranga olivacea,* in two breeding seasons, showed that the spatial selection of dominant males is associated to the size of the patch. The most fragmented and smaller areas are restricted to younger males with less territorial claim (Fraser & Stutchbury, 2004). In these studies, the more fragmented habitats have less ability to attract individuals, a lower occupancy rate and an annual inter-correlation with the isolation. Other evidence from these studies is related to the composition of generalist species in the very small patches (André, 1994). The findings suggest a positive relationship between the size of the patch and the persistence of the species (Vos et al., 2001). The opposite it also confirmed, species distributions are frequently missing in small habitat patches with less connectivity. It also suggests the existence of a critical size that changes according to habitat type and species (Fahrig, 2002).

1.2.2 Configuration indicators

Configuration metrics assess the complexity of forms (e.g., spatial arrangement of different patch types). Configuration metrics may measure the degree of connection or in opposite view, the isolation of patches in the matrix (Tischendorf & Fahrig, 2000; Moilanen & Hanski, 2001). The configuration metrics can be grouped in two categories: based on inter-patches distances; and the ones that compare the overall spatial pattern, or spatial texture. The computed metric can assess the geometry of the patch, which can be also measured by the fractal dimension.

Table 1-2. Example of available configuration metrics

Name	Symbol	Description
Perimeter-area	SqP	Normalized ratio between the value of perimeter and area of habitat patches
Contagion	*CONT*	Assesses the degree of proximity between a set of cells of a map
Isolate Connectivity Index	*ICI*	Describes the neighbourhood configuration of landscape elements relative to a selected isolate based on the proximity, shape, size and position of patches (Kininmonth et al., 2004)
Graph theory	‘‘patch-based graphs”	Keitt et al., (1997); Urban & Keitt (2001)

Isolation or the nearest neighbor distance, measures the shortest edge-to-edge distance between patches of the same category (Moilanen & Nieminen, 2002). It is simple to compute and associated to the metapopulation theory, where the result of dispersion and colonization decreases as a function of the distance. A simulated empirical experiment confirmed that increasing interpatch distance significantly decreased connectivity flows (Goodwin & Fahrig, 2002). Other relevant metrics related to species or process-specific functions are *Connectivity* or *Nearest Neighbor Distance* *variations* to buffer areas or surrounding habitats (Rutledge, 2003). Spatial pattern metrics aim to supply a measure of the overall complexity. A commonly cited example is *Contagion* that measures the degree of adjacency between cells (similar class are aggregated), but sensitive to resolution effects. A possible alternative is *Patch per Unit Area*, which is not scale dependent. Patch *Cohesion* shows significant levels of correlation in models of dispersal. Patch resources are different for each species, so thus patch cohesion will differ (Rutledge, 2003).

The *Shape* is usually described by the relationship (ratio) between perimeter and area. A habitat patch elongated and narrow is more exposed to neighborhood relations and less protected, with index values close to 0. In the opposite direction will be a habitat patch that approximates geometry of a circle with an index value of 1, this means a core protected. The shape of a habitat patch in conjunction with its size determines the higher or lower border effects. The shape may also have a funnel effect directing individuals in a certain direction. This condition was measured in studies of mammals; certain locations have a higher number of road-kills due to the patch "plumber" (Serrano & Sanz, 2002).

1.3 Scale and context

The scale of analysis and context of sampling matrix (non-habitat and habitat) are key components for the assessment of fragmentation and connectivity (Gardner et al., 1987; Wiens, 1989). The scale is relevant to the distributions of environments predictors and species patterns. Two important factors are related to the measurements of spatial heterogeneity: *Grain,* also known by the resolution of the data or minimum mapping unit, and *Extent* being the size of the studied area (Turner et al., 1989).

The outcomes are largely related to the 'scale effect' of habitat analysis. As measured by Riitters et al. (2000), the fragmentation metrics are also sensitive to pixel size (grain), spatial scale (i.e., window size definition), and the attribute scale (i.e., the categorical classes). Results indicate that for large scales, the territory has increased fragmentation and our ability to assess the territorial fragmentation decreased with decreasing scale of analysis (Keitt & Urban, 1997). Some metrics (i.e. *CONT*) show a strong relationship of dependency on the represented classes (Wu et al., 2002). Usually, increasing the class representatively increase fragmentation by introducing more patches in the analysis (Turner, 1989).

The developed models usually focus on a multi-functional and home-range approach, in which the scale has implications. In multi-functional approaches, the fragmentation of the habitats can occur (i) at the global scale with global implications in the distribution of species, or (ii) at population scale with implications for the movements and relationships between populations of the same species. In the home-range approach, we consider implications in the trophic and reproductive functions of the individuals (Franklin et al., 2002).

The modeling tests and empirical data seem to confirm that species have different scale-dependent responses to habitat fragmentation (Vos et al., 2001). Base on the complex of ecological processes and patterns having influence across multiple scales (Rutledge, 2003). Both a process and a parameter can be relevant at a given scale and may not be significant or even lose their predictive meaning at another scale (Turner, 1989). One possible way to model scale effects is to create models with hierarchical structure, considering different levels of predictors separated into submodels (Mackey & Lindenmayer 2001). It is possible to make scale-specific inferences by the association of regression and wavelet analysis, using wavelet transformed predictor variables (Keitt & Urban 2005).

The scale factor is accentuated when it comes to identifying different relationships among living organisms. The results show that connectivity is in part dependent on the scale of the habitat use by the species. This means that when the species make a limited use of territory, the habitat configuration is very important to connectivity, especially to sparse population (Rantalainen & Haimi, 2004). In the opposite, species with high mobility between distant areas are not very dependent on the individual configuration of the spots. Species with disabilities are defined on a scale of filtering "percolation transition" beyond and below which they pose population dispersal capability limitations (Keitt & Urban, 1997).

1.4 Spatial connectivity

The spatial connectivity corresponds to the degree to which the space promotes or hinders the movement of species. Spatial connectivity is related to the distance between suitable habitat patches and from the relative resistance of the matrix. The use of "your living space" is very diverse and can vary with gender, trophic requirements, reproduction, size, weight or social behavior (Chetkiewicz et al., 2006).

The promotion of mobility is of utmost importance in ensuring the needs of feeding and reproduction, and for guarantying the acquisition of resources and permutation for genetic diversity. The examples demonstrate that to assess the movements, it is necessary to take into account both the physical distance and the factors of barriers (Chetkiewicz et al., 2006; Fortuna et al., 2006). Having habitat use and movement patterns of species in the spatial matrix provides a wealth of opportunities to enhance the linkage between species and functional understanding of landscape matrix (Turner, 2005). The development of a new infrastructure may be irrelevant to one species and have negative results for another.

The promotion of spatial connectivity is traditionally associated with the species of fauna, related to the premise of mobility, within its possibilities, to select the areas of transit. The bibliography has many names for areas of transit and applied concepts, like 'stepping stones', 'movement routs', 'corridor', 'linear habitats', 'landscape routs', etc. The ecological corridor definition applies to linear structures formed by fragments of habitats in the spatial matrix and ensuring the mobility of the species (Tischendorf & Fahrig, 2002; Chetkiewicz et al., 2006). There is no single definition with universal validity to the concept of spatial connectivity; however, this issue is associated with the planning of corridors and/or green corridors. Spatial connectivity is very fashionable in landscape ecology and with much expression in urban planning.

It is not known to a quantifiable level, how to match spatial connectivity to promote conservation and biodiversity. The conducted studies thus far, with field experiments, have constraints in assigning connectivity values (Davies & Pullin, 2007). The passage of the theoretical validation based on controlled experiments is still a very experimental task (McGarigal & Cushman, 2002). One may ask, why model the effects of fragmentation and spatial connectivity? The answer is there is a belief that they are key factors in the growth and persistence of species through the success of its individuals (Simberloff, 1992).

The construction of spatial models seems to be a useful tool to test and measure some parameters of the habitats and propose solutions to conservation (Moser & Jaeger, 2007). The methodologies and techniques for the characterization of ecological functions depend on the questions requiring answers, their adaptation to the universe of the used variables and complementarities between them (Segurado & Araújo, 2004).

1.5 Geographic modeling approaches

Remote Sensing (RS) and GIS offer a vast possibilities and structured approaches in spatial analysis and modeling. These tools have been applied in research issues and sustainable planning (Botequilha & Ahern, 2002). They are instruments for developing spatial analysis models (Wegener, 2001), with an applied capacity to generate and processing data of different spatial and spectral resolution. Geographic modeling, helped by the use of spatial models, has an increasing importance to assess habitat fragmentation and connectivity. Spatial models have the ability to generate alternative scenarios of representation and simplicity in the results interpretation (Botequilha & Ahern, 2002). The models can incorporate uncertainty scenarios that allow us to compare solutions (Burgman et al., 2005; Rae et al., 2007).

New forms of spatially environmental data and also processing algorithms have improved the modeling species patterns distributions. It is also fomented by the demand of mapping products for research, conservation planning and land management (Elith & Leathwick, 2009). This is to take advantage of opportunities to develop and analyze models where the responses of species individuals can be compared at different temporal and spatial scales.

The model solutions are base on complementary methods and techniques, by the facts that are very specific models and there is no universal solution implemented. The use of neighborhood relations in orthogonal space of raster format is a very common option. Usually and conveniently, to calibrate the parameters and circumvent the technical and analytical limitations, it resorts to expert opinions based on observations of populations of species in the field. Although very limited, these models help in analysis and representation. The generated models allow us to understand the implications of the spatial dynamics process-patterns interactions in the distribution of species populations (Hargrove & Hoffman, 2005).

The latest adopted methodologies are based on approaches of explicit spatial relations. These models arise sometimes in association with the mobility of the individual, focused on simulate the individual movement and their relationships with patterns of land use matrix. Optimal paths (directions-angles) and graphs analysis, defined some methods of these models. The proposed modeling approaches include the territorial systems of reaction-diffusion in controversially isotropic space (Wegener, 2001). We are realizing a set of techniques for simulation and quantification of the movements, which can detect patterns of behavior in the habitat (Chetkiewicz et al., 2006).

1.5.1 Modeling species spatial connectivity

The movements between scattered fragmented habitats, is not only a function of distance, but also of spatial resistance. Resistance surfaces represent hypothesized relationships between landscape features and species flow. These are based on underlying functions, like the relative abundance or movement probabilities in different land cover types (Adriaensen et al., 2003; Ray et al., 2002; Spear et al., 2010). Some developed algorithms calculate resistance surfaces according to the distance between groups of target cells 'pixel'. In essence are functions of radial distance, the distance operator can simulate and integrate frictional effects or barriers. This is a typical approach of GIS to estimate the optimal path between two set points. The models of 'resistance surfaces' can be calculated for the friction in the movement, and also for the risk associated with the phenomenon of spatial dispersion. This approach assumes that the motion of the individual is properly associated with the habitat, which has not been completely proven yet.

An increasingly employing and tested technique is the network or graph analysis. The network analysis is a modeling technique frequently used in transport or Web research, with a growing ecological application. Implementing the principle of the graph theory to spatial status (spatial graph theory) is possible with this approach to model the connectivity between patches (patch-based graphs) compared with the observed movements of individuals (Keitt et al., 1997; Urban & Keitt, 2001; Dale & Fortin, 2010; Galpern et al., 2011). The network analysis in association to percolation theory has been proposed as a useful technique for research on connectivity thresholds (Keitt et al., 1997). The threshold is the point (Figure 1-2) at which there is an abrupt change of the measure property, with important impact on the system equilibrium (Groffman et al., 2006). The basic question is: “How many random nodes (paches) can be removed before a network loses connectivity?”

Patch-based graphs are models of functional connectivity; the *links* represent a functional response of the organism to the landscape (Galpern et al., 2011). The analysis of interconnections, through representation in the network, can identify the functional connectivity of a network structure composed of nodes and links. Links connect nodes only when the distance is below some ecologically-relevant movement threshold for the specie. Above the threshold, patches are connected; below the thresholds, patches are isolated. The models are built using this technique to evaluate the importance of individual spots and training for territorial clusters (Jordan, 2000).

Network analysis has been proposed to model connectivity in habitats reserves, allowing the assessment of conservation strategies for multiple species (Fuller et al., 2006). Networks analysis shows that disconnections occur (removal experiments) as a consequence of nodes (i.e. patches) lost, or connections occur if nodes are added. While removing some patch in strategic locations means that individuals lose the capacity for mobility. The removal of a patch may have local consequences and also effects on global connectivity. The results express the importance of certain patches in the overall structure of the territory; this has direct applications for planning (Pascual-Hortal & Saura, 2006).

Network analysis may also be applied to connectivity risk assessment, where species invasion is a concern (Margosian et al., 2009). If we understand the critical link threshold of the species, we may plan the control and the prevention of its diffusion (Estrada-Pena, 2005). A possible approach is to identify a critical link threshold, (Figure 1-2), which is associated to the threshold effects, at which the space generally becomes disconnected for the focal species. The spatial spread of a process like fire may exhibit threshold responses of drivers' presence, distribution and connectivity proprieties. Below or upon critical thresholds, fire extent depends on the conjugated presence of drives (i.e, flammable fuels across a landscape, whether conditions) and spread without adequate spatial connectivity (Turner and others 1989; Turner and Romme 1994, IN: Groffman et al., 2006).

The relation of landscape pattern over the behavior is documented by empiric studies of diesis diffusion. The spread of an invasive disease on patches located along intermittent rivers and crossed by roads were more exposed infection than those patches without road crossings (Jules et al., 2002). As previously stated, the infrastructures of road communication are largely responsible for the habitat fragmentation, but for some species, usually exotic, they play an important role in dispersal dynamic (Hansen & Clevenger, 2005). In Portugal one of the paradigmatic examples is the case of species of Acacia that disperse quickly, a result of their ability to capitalize on the movement of vehicles to transport seeds and settle in new territories.

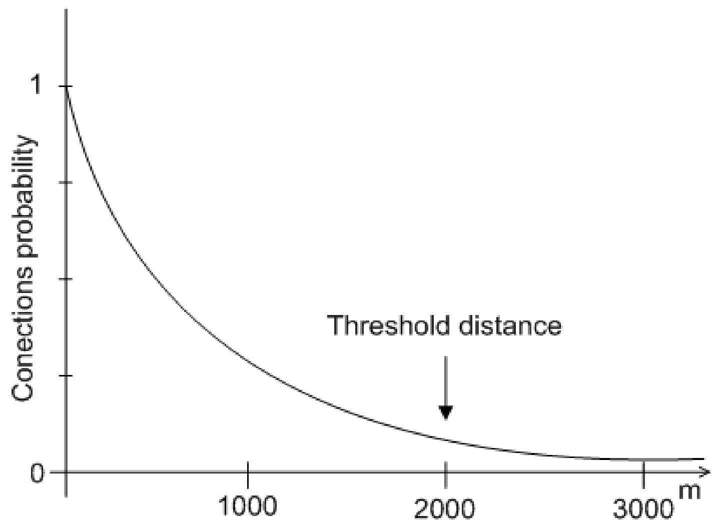

Figure 1-2. Function of threshold distance; the value of critical thresholds is associated to the focal specie, dependent of particular process and landscape, but the occurrence of the threshold is not.

1.5.2 Modeling species patterns distribution

The goals of modeling species patterns distributions or species distribution models (SDMs) are related to ecological process (Turner 1989; Wu et al., 2002; Bergon et al, 2006). Modeling species patterns distributions makes the convergence between ecological and natural history traditions concepts with recent developments in statistics and information technology (Elith & Leathwick, 2009). The main assumptions of modeling patterns distributions are; that species are at equilibrium with their spatial environments, and that important environmental gradients have been well sampled (Elith & Leathwick, 2009; Guisan & Thuiller, 2005; Guisan & Zimmermann, 2000).

Usually, there are three approaches to modeling: (i) Theory-based approach that aims to achieve general laws to explain general phenomena. Predictions laws of theory must be tested often in conceptual models using experimental or surveyed data. (ii) Process-based approach is based on a mechanistic process-description and the models are parameterized for few species, cover the range of metapopulation, (iii) Pattern-based approach describes species distributional patterns relating data of species distributions to environmental predictors, using regression-like or classification techniques. The two former approaches are also embedded in a conceptual theory, starting with the description of either process or pattern (Schröoder & Seppelt, 2006).

The distribution patterns are evidence of the interplay between species relationships with geographical and/or environmental gradients. The geographic space is defined by the two or three dimensions. Map coordinates and environmental space predictors are potentially multi-dimensional (Elith & Leathwick, 2009). Model-based interpolations are predictions of species distributions to new sites, done within the general space-time frame and range of environments in the sampled training data. Correlations of predictor variables are supposed to be stable in the geographical domain (Elith & Leathwick, 2009). Usually these interpolations are used for mapping goals, management and planning conservation or selecting habitat suitable (Guisan & Thuiller 2005). Prediction to the outside of the sampling, into a new space-time environment is called extrapolation or forecasting (Araújo & New 2007).

There are several statistical techniques to model the pattern of distribution and occurrence of species in relation to environmental variables. Most of statistic methods are regression-like, based on the premises that species distribution can be modeled using additive combinations of predictors. However, no one knows for sure what mechanisms govern the distribution patterns (Segurado & Araújo, 2004; Baveco &

Jepsen, 2005). The modeling techniques allow us to consider the correlative relations between phenomena, yet with a low degree of certainty over its causal determination. Correlative models are perhaps the most comprehensive and most used to generate profiles of distribution patterns. The logistic regression models are among the most frequently used. The Generalized Linear Model (GLM) and the Generalized Additive Model (GAM) techniques allow us to estimate the values of a variable (e.g., species presence or abundance) considering the relationship of dependence on independent variables (Koper & Schmiegelow, 2007).

There is an increasing use of neural networks, with modeling the unknown locations. The absences of species can be achieved using so-called pseudo-absences, for example points located randomly. An alternative technique is based on Principal Component Analysis, recognized as Ecological-Niche Factor Analysis (ENFA). ENFA belongs to environmental envelope models, and define the hyperrectangle that frame species records in a multi-dimensional environmental space (Elith & Leathwick, 2009). The main advantage in using this technique lies in that it enables the modeling based on knowledge of the species presence distributions, without the knowledge of the absences (Hirzel & Hausser, 2002). Nevertheless, predictions are more robust if presence-absence data is available (Elith & Leathwick, 2009). Other interesting techniques are grouped into machine learning methods class, guided by maximum entropy modeling which optimizes the relationships between variables (Phillips, et al., 2006).

The use of candidate predictors and validation of the models are common issues of concerns. Some authors argue that it is useful to include all possible predictors' variables and let the model performance identify their importance. On the other hand, some believe that it makes sense to use predictors with ecological meaning to the target. Base on this fact; predictors are proxies, and the analysis is correlatively applied, as it is always possible to fit statistics prediction relevance, but without ecological ones. Usually model selection is base on *p*-values, but in the most recent studies it has been a growing weight on AIC and multimodel inference (Burnham & Anderson, 2002). Prediction models need to balance the fit of the training data in mirror to new cases predictions. Information criteria like Akaikes Information Criterion (AIC) quantifies this balance assessment, by explaining variation against model complexity. In machine learning methods, it uses a cross-validation within the model-fitting process and for model evaluation, to test data performance (Elith & Leathwick, 2009).

1.6 Methodology approaches

This dissertation thesis explores some aspects in the relationship between habitat fragmentations and connectivity on species patterns distribution. The overall goals are to understanding and identify some aspects of relationships and interactions between patterns-processes. The thesis is supported by case studies that analyze the consequences of habitat scarcity, loss, and modification which result from human activities. The habitat transformation is result of the effects of Alqueva reservoir, or dissemination of communication and transport facilities. The aim is to address the following questions:

1) How can information management support insight maps of species distributions?
2) How does faster land cover changes influence pattern distribution?
3) How do barriers affect distribution and population dynamics?
4) How is habitat related to species pattern distribution and connectivity?

The work was guided by the factors set out by geographic modeling methodologies, with unusual applied spatial statistics techniques. An example of the techniques employed is the point pattern analysis of species distribution, which is relatively well-known, but rarely tested (Legendre & Fortin, 1989; Legendre et al., 2002; Perry et al., 2002; Wiegand & Moloney, 2004). Network analysis (graph) is another example of a technique rarely used or tested with few applied application in spatial ecology (Pascual-Hortal & Saura, 2006; Urban & Keitt, 2001). Some methodological purposes are applied in the article sections. This is a thesis with applied study cases, with some material outputs, as described in the example in the next section.

2 BIOGEOGRAPHIC DATA MODELING

“*While exploration has its risks, it also has its rewards, the most precious of which can sometimes come from the search as much as the find*” D. Tomlin (1991)

Abstract

Monitoring the species location is an essential step to natural resources modeling and management. Among these, biological resources aim special concern because data availability is highly limited by a number of sampling logistic constraints and catalog. As a matter of fact, data availability is one of important limitation to knowledge and, as a consequence the development of new concepts in natural resources. Data organization in digital format is a common practice in our days, and has the power to contribute to timely decisions process in knowledge base systems. With this article it is our aim to present a Biological and Geographical application tool (BioGeoDB) to provide case studies support. Until application development data storage was been recorder into fragment system, with no updatable structure and missing information consequences. We intend to show the application potentialities uses, the developed model and articulation between subsets. The developed application use a species database associated with a desktop map environment. Application generates datasets reports and thematic or modeling cartographic maps display. BioGeoDB has been developed with the purpose of making compatible different datasets, derived from fieldwork studies of biodiversity monitoring programs, and also support future published studies.

Keywords: Database design, geographic information system (GIS), monitoring, species, taxonomy

2.1 Introduction

Digital alphanumeric datasets have been collected and organized as a fundamental and basic instrument for decision making in knowledge process. The development of databases gives us the possibility to register species sightings with confident spatial reference. This has been the aim of some works at different geographic scales, for example the Banc de Dades de Biodiversitat de Catalunya (Font et al., 2004), Europaea Fauna (Fauna Europaea, 2004), National Biological Information Infrastructure (Campbell, 2003), Species 2000 (White, 2003). Databases are useful to identify gaps, to congregate and integrate data, to prevent duplications of efforts, and to provide information to support studies at different issues levels.

Legislative frame and environmental health indicators demand quality information of species location and natural resources. Research institutions and nongovernmental organizations (NGOs) accumulate substantial species records, from fieldwork or bibliographic catalogs. Nevertheless, strategic information is not always easy to find, and therefore the efficient management is essential to identify relevant information in the decision making process. Collecting records does not always signify accessing to the information: Why? There are many blocking reasons; most of them related with organization and quality (e.g. corrupt files) and management issues (e.g. lost files). Quality is an essential aspect of information competitiveness (Michael et al., 2003). Recording biological species involves different issues and computer science problems: as scale collecting, temporality, heterogeneity and validity.

Usually, the Universal Transverse Mercator coordinate system (UTM) of 10km grid is the reference scale of field sampling data unit. Although, we advocate a more precise location recorders, like point surveys (visual/trapping) as main methodology to collecting data of species. The used methodology must be associated with the species group characteristics, e.g. sampling bird species it is usual to stay in a site or cross visual transects. Mammals are usually identified by residual fingerprints, e.g. deject or landscape marks. Beetles, dragonflies or butterflies by traps. Species occurrence depends also from temporality issues, like season of the year, and day and night cycle. All these attributes should or could be register, to allow analyses relationships and generate new information.

Biological data in publish paper and digital support started to be available from different sources. It was an opportunity to deal with thousands of no structured records.

Organized data enable better understand of species and habitats pattern distributions. The registration of species allows us to assess and to quantify biodiversity at different scales (space-time), with obvious potentialities in the definition policies (Maier et al., 2001). Long-term data series of species communities and populations improve decisions of present trends (Bowker, 2000). The development of informatics tools is essential to exploring biogeographic data (Nielsen et al., 2000).

Our data sources provided from fieldwork studies carried out between 1995 and 2005 or still in progress, mainly in Alentejo region. Data collections were first keep in support files (usually in sheet files) to all groups of species and geo-reference with different scale accuracy and field methodologies. As a matter of fact this sheet files were disperse in a fragmented data bank, in different computers with no logical and metadata edition. Fragmented data bank means functional and updated information lost. Available data does not mean available information, because sometimes we didn't know that data exists.

How could data modeling produce better information? Give correspondent solution to the increasing biogeographic data collection. The solution should include a visual data management in desktop map environment and cartographic modeling. Databases of species cannot exclude geographical questions and therefore must allow the geolocation for modeling and management purposes (Salem, 2003). Managers and nature conservation planners need tools to link available data of species diversity to critical measure of the sustainable conservation. The association of databases with GIS tools increases data utilities and promotes more general intentions of current research, making possible the emergence of new interdisciplinary fields of knowledge, allowing holistic point of view.

BDBioGeo was the natural follow up of a project created in 1996, called Alentejo's BioGeographic Unit (UNIBA). This former application was a regional database. UNIBA did not respond to new demands, as consequence of constrains and limitations in spatial modeling functions. It was decided to develop a new model, with extended functions, and to whole Portugal mainland. BDBioGeo was also developed with the idea of data center to support future studies in the frame of the PhD. research.

2.2 Objectives

We identify three main goals:

a) Record fragment datasets from monitoring and biodiversity studies that have not been published yet;
b) Record bibliographical data (published) on the distribution of species in Portugal mainland;
c) Modeling species data with geo-reference location and habitat sources.

With the application development we expect to improve knowledge about:

- Fieldwork facilities in oriented surveys in Portugal mainland;
- Develop new studies with modeling approach of species habitat fragmentation and connectivity;
- Insights of new questions related to data environmental management and planning.

2.3 Design application solution

The solution to achieve our goals was found in dual architecture of software productivity integrated application, based on commercial software as Relational Database Management System (RDBMS) and desktop map (Figure 2-1).

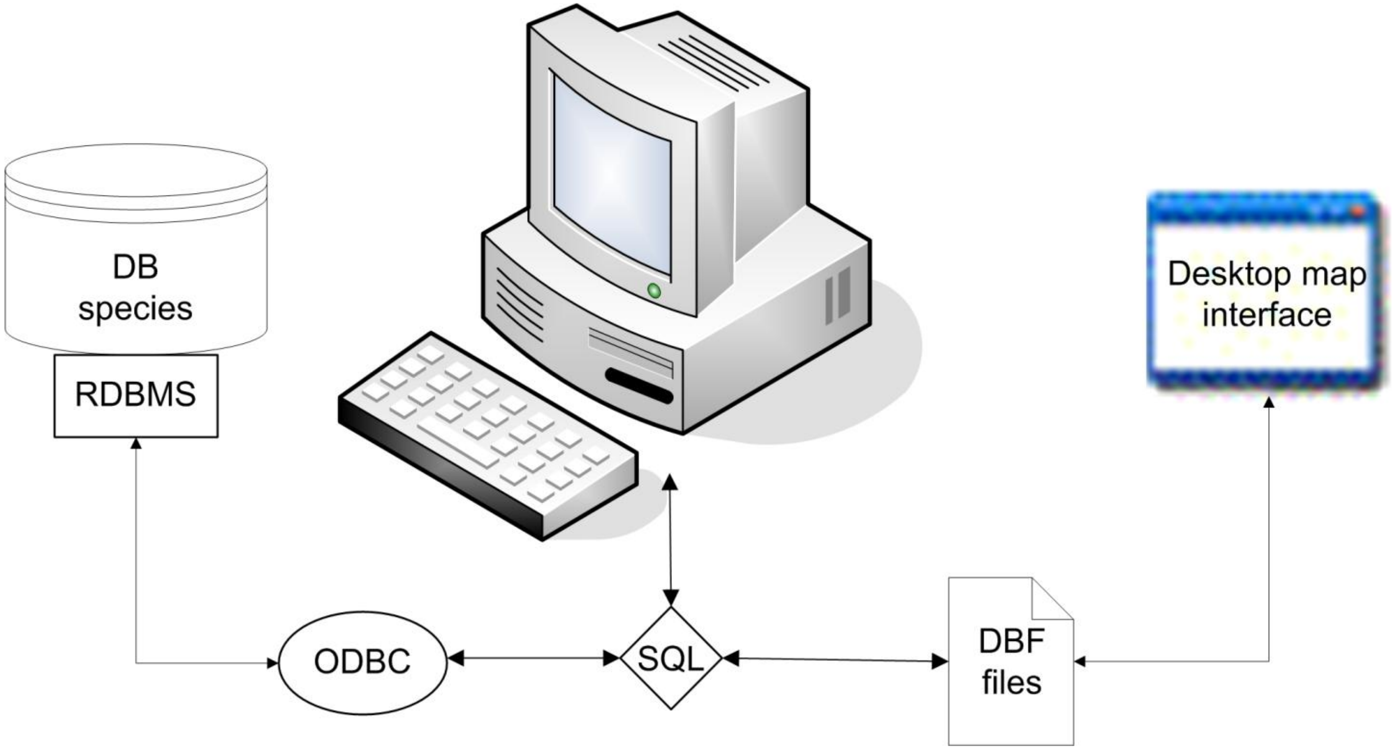

Figure 2-1. Dual software architecture based on RDBMS and desktop map

In this model, applications are dedicated to tasks, the RDBMS deals with the alphanumeric data in a way independent of desktop map. This means that decisions supported answers can be providing based on data management, as it will be showed in forward examples. The connection and data transfer between the database and the desktop map was made by the Open Database Connectivity (ODBC) protocol, which is a middleware of sufficiently simplified use (Adam & Gangopadhyay, 1997). With this type of application model, the alphanumeric and the graphic data are linked together for information flux (Pereira, 2002).

2.3.1 Conceptual database model

The database was expected to make compatible a set of flexible premises, between the direct data sources (field studies) and indirect data sources (bibliographical). Conceptual model and translated physical database start with identification of required variables and those of essential registration (Figure 2-2). A data collection includes the identification of the species, site location and date of the sighting observation, often the year. As we will see forward species attributes are split in tables, join information means go through several tables.

Users interact with tables; the database is structured according to a relational model (Date, 1986; Silberschatz et al., 1997). This database provides analytical and generalized use principles, with specific goals structured according to the analysis needs, in a long-term perspective. Since at present it is still a restricted database, its design has been conducted taking into account analytical aspects, storage very large registry sets without major concerns to procedural questions.

In summary, the principles that have underlined the design of the database model, has been:

- Easiness to work (simplicity and pre-defined queries)
- Easiness of maintenance (update)
- Integration with desktop map

2.3.1.1 Entities

The entities obey of hierarchy structure in relational model and organized as a function of species taxonomy. The model was oriented to SPECIE (Figure 2-2) entity level, which represents the core of the alphanumeric attributes. SPECIE entity plays a central role, connecting the relations upward (upper entities), and downward (records and relations with the geographic entity) in the "*chain model*". The SPECIE entity is also a checklist for the species set placed exactly before the insert records, controlling data quality.

Species are registered on a vertical form, to which a unique numeric code is attributed without mismatch. Each new species is forcibly linked to a hierarchical superior taxonomic record: for example, a new species name must belong to an already existing genus. If specie belongs to a new genus, the genus should be first insert and validated. The same procedure is required for higher taxonomical levels. This rule is the result of the application of integrity law that hinders the existence of orphan records, i.e., without link (Codd, 1990). The SPECIE attributes also include video, photo or sounds that confer to the database visual and sensorial analysis.

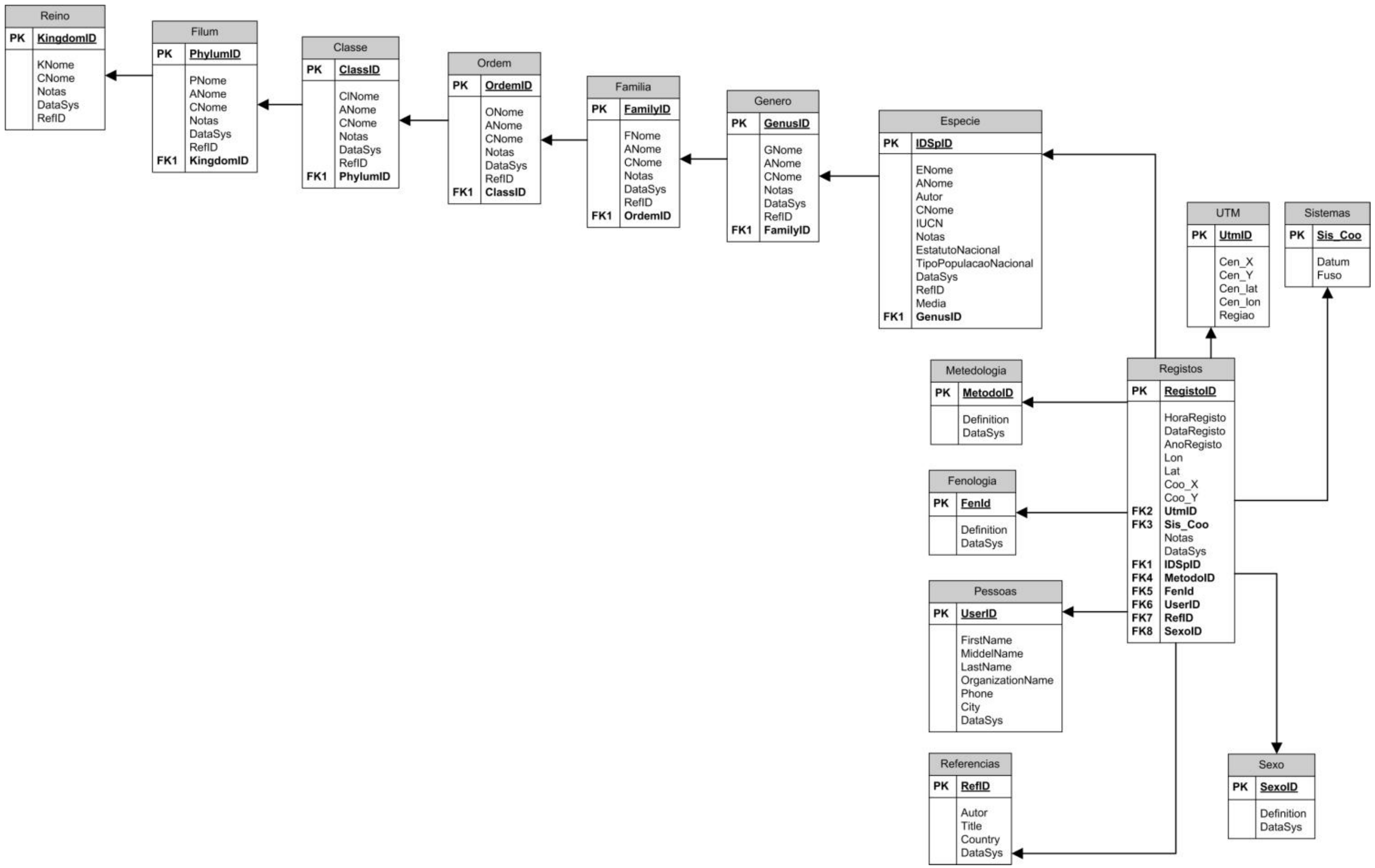

Figure 2-2. Alphanumeric data model, the flow between the entities reflects its relationship

The relationship between different entities is carried out through the use of primary keys in posterior entities, for example (KINGDOM.KingdomID in PHYLUM.KingdomID). This structure is based in one-to-many relationships (1:n). Records are all stored in the RECORDS entity, where species' observations including location and date. Parallel to this hierarchical structure, there are some horizontal controls and validation variables, which are all directly related with the RECORDS entity. Grouped within a set of five categories:

1. SAMPLING
    - METHODOGY – different species monitoring methodologies used in field survey;
2. BEHAVIOR
    - BEHAVIOR – behavioral characteristics of the species, with particular focus on birds;
    - PHENOLOGY – phenological characteristics of the species, with particular focus on birds;
3. CONTROL
    - REFERENCES – data sources;
    - USERS – identification and the skill quantification of the researcher;
4. AMOUNT
    - ABUNDANCE – number of observed individuals that is registered, using an ordinal scale;
5. GEOGRAPHIC
    - COO_SYS – geographical coordinates of point sampling records;
    - UTM_GRID – Universal Transversal Mercator (UTM) 10x10 km grids, identified by unique ID's;

- HABITATS – habitat location;

6. REPRODUCTION

- AGE – age of individuals when sampling methods allow (applicable in mammals and birds);
- SEX – sex of individuals when sampling methods allow (applicable in mammals and birds).

The geographic identification (ID of UTM 10km grid) is replicated in the RECORDS entity, which makes relationship between the alphanumeric data and the spatial feature.

2.3.2 Desktop map frame

Desktop map interface was customized and programming based on Avenue™ language (Figure 2-3). The developed interface allows the user to direct query database records in different spatial or alphanumeric criteria. The automatic generated outputs allow users immediate contact with species distribution or spatial queries. Administrative boundaries or other represented features define some of must usually spatial queries. Queries can be made in different aspects of records details. The present application version allows some of regular queries and demands:

- What species present in a spatial feature?
- How many records species present in a spatial feature?
- What is the distribution of identified specie? (Figure 2-4)
- Neighborhood analyses (Figure 2-5)

- Species' richness at UTM grid or point
- Automatic reports of taxonomy

Spatial dimension of surveys tend to be detail as possible. This means that when is possible the species sightings are recorder as geographic point or planar coordinates. However, for a better efficiency in record visualization and systematization, the use of a non-projected system (geographic system) is desirable. Record coordinates sources providing from GPS units and field maps location. As mention before, species identification methodologies have a relation with spatial layers. In the less accuracy geo-reference scenario, species must at least belong to a UTM 10km grid. Without spatial reference is impossible to insert the specie record. This constrains as others implemented, validate and guarantee data quality and spatial location.

Implemented algorithms allow neighborhood spread functions to identify the species probability distribution (Figure 2-5). Based on specie distribution we sample potential distribution pattern. The values are calculated from the focal sum of near eight neighbors (Tomlin, 1990). This facility gives us the opportunity to investigate working patterns hypotheses. Habitat of species distribution is identified by and overlay theme and the record description. With the species distribution we cross other themes and new resulted information.

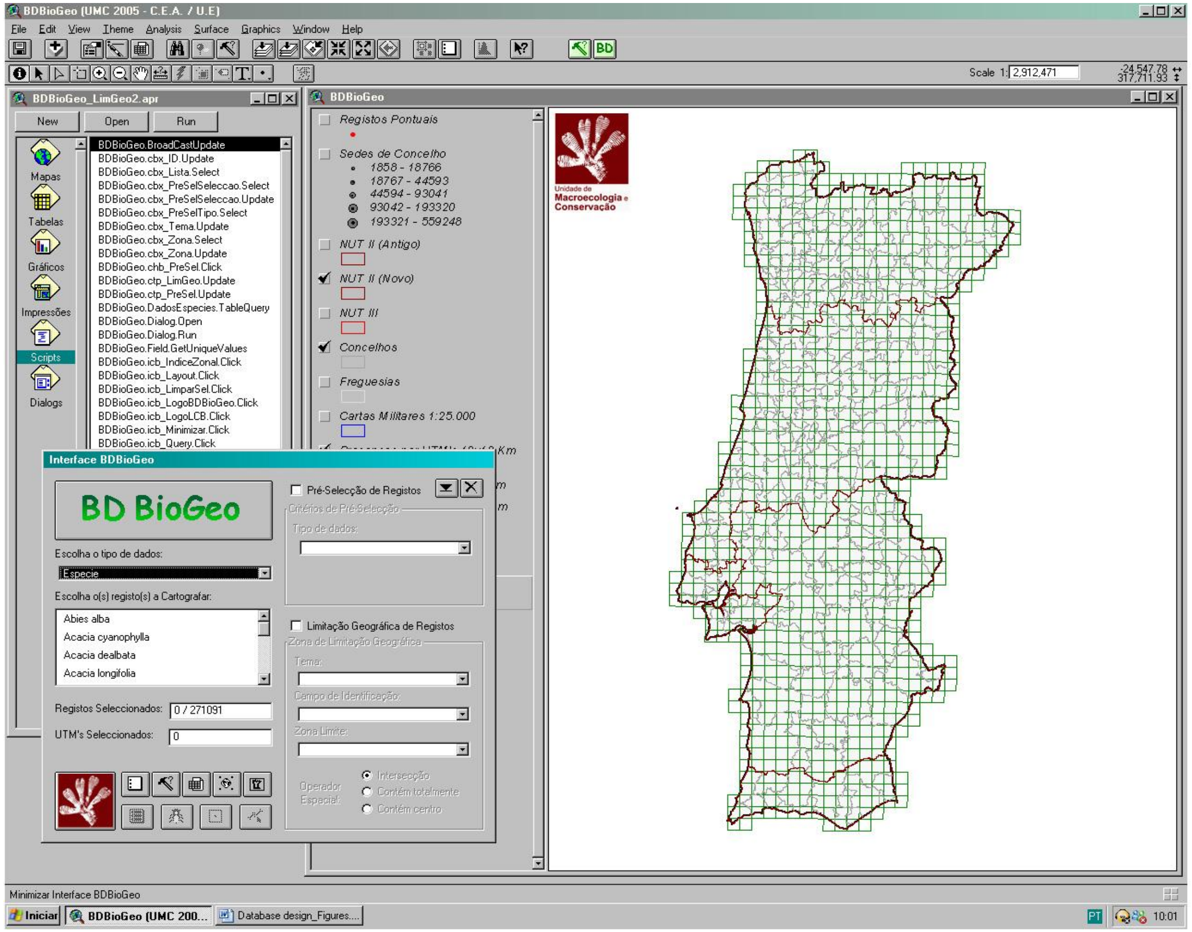

Figure 2-3. GIS interface menu where the users chosen species selections. Selections can be executed from different attributes (e.g. name, family, distance, administrative boundary, etc).

2.4 Results

The most obvious and useful advantage of the BioGeoDB, was the centralization of all species records in a single database. The application developed allows an easy delimitation to identify the species distribution, its occurrence or abundance at a given location, as well as the number of registered sightings.

With the centralization we make use of a fundamental tool in information handling, indispensable to researchers and institutions. Make use and manipulate information for investigation purposes; modeling species, namely their response to different scales of sampling distributions, monitoring, resource and habitats management, ecological land planning and support decision making, etc. Most BioGeoDB application demands are the academic studies, like graduated thesis or papers contribution. The temporal (records with date) and spatial (with coordinate of species position) dimensions are crucial for the progress of such studies. This homogeneous dataset have also the virtue of allowing validation of bias species' listings, by filtering at the very moment of records input.

The BioGeoDB includes at the moment a total of 271296 registers, in a set of 2794 distinct species, observed in 996 distinct UTM grids (in 1029 possible), and 7153 distinct points. Records of terrestrial macro-invertebrates species are of special interest, since they usually absent in similar databases. As a recent article shows, mammals and birds are usually the groups of research attention (Knegtering et al., 2005). BioGeoDB database includes a set of 142 species of Insecta and 99 of Arachnida. As for the comer groups, a comparison with other national and international sources of species data for Portugal mainland shows similar species representation (Table 2-1). For this comparison we considered only the most commonly studied groups, since there are no references for the other groups. Some of the differences (Amphibia and Reptilia) are explained by recent changes in species taxonomy. For example, the Europaea Fauna considers some new species, not yet included in the majority of taxonomical databases. (Instituto Conservação da Natureza, 2005; Ramos et al., 2001)

Table 2-1. Number of species of the main groups in different sources of data

Database source	Amphibians	Birds	Mammals	Reptiles	Total
BioGeoDB	**18**	**357**	**78**	**29**	**482**
ICN	17	274	89	27	**407**
Fauna Europaea	20	387	68	36	**511**
Iberian Fauna	17	214	63	29	**323**

Conclusions of species richness and distribution should account data sources monitoring efforts; in this case we have much more data in Alentejo region (Figure 2-6). The cartography of species is a working instrument for the sustainable use of resources, allowing the execution of useful syntheses.

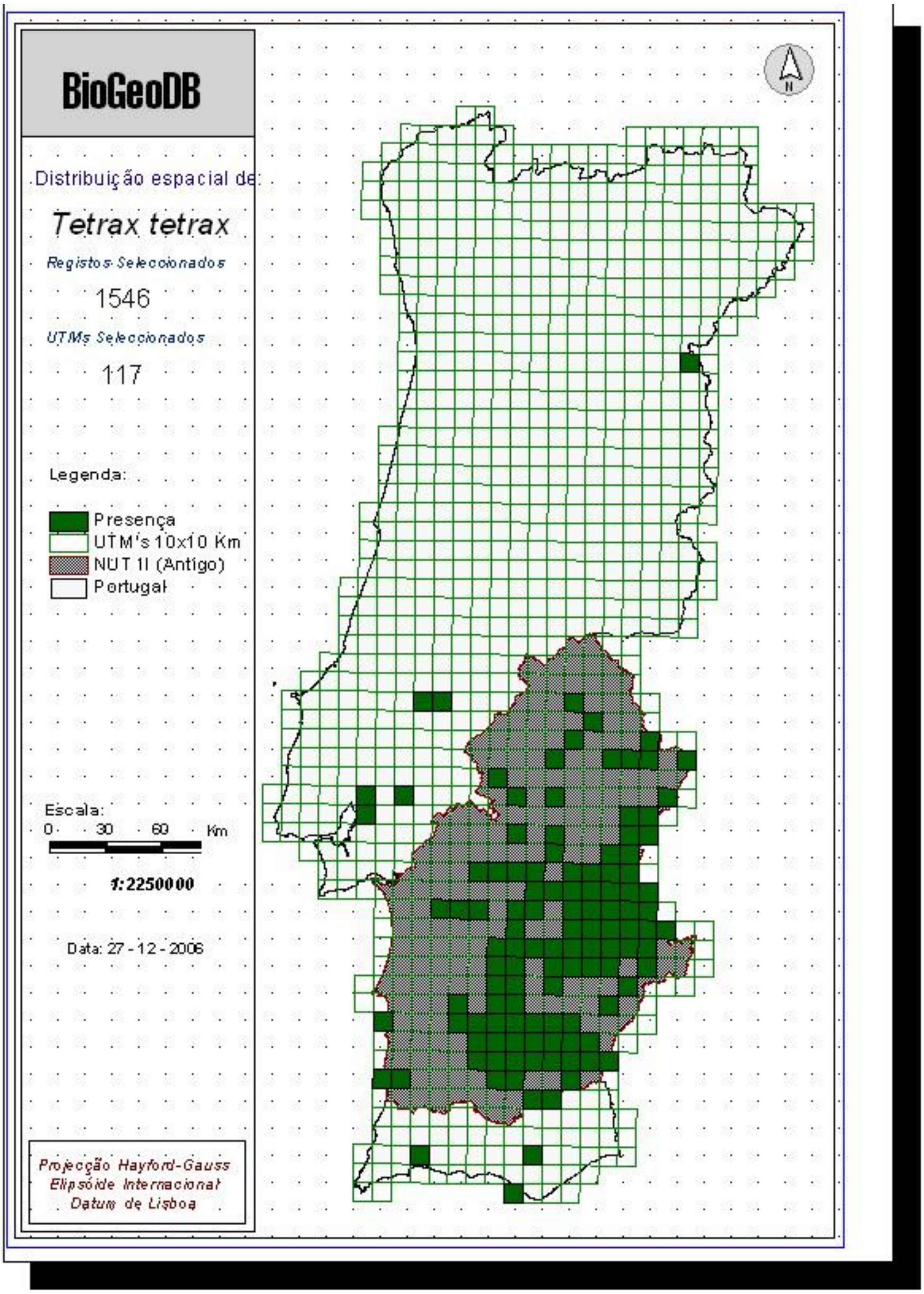

Figure 2-4. Distribution (solid green) of steppe birds *Tetrax tetrax*

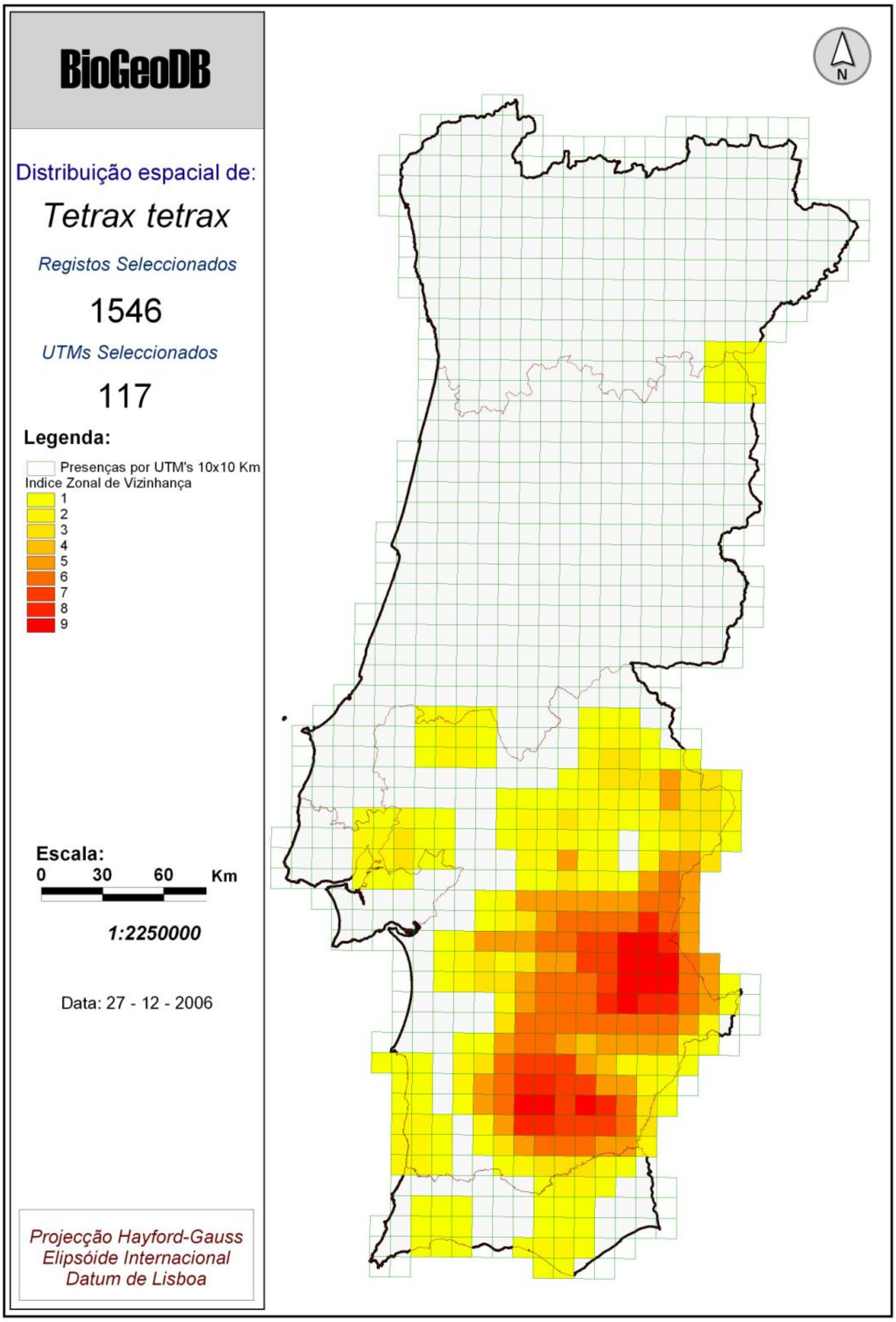

Figure 2-5. Neighborhood function of *Tetrax tetrax* distribution grids.

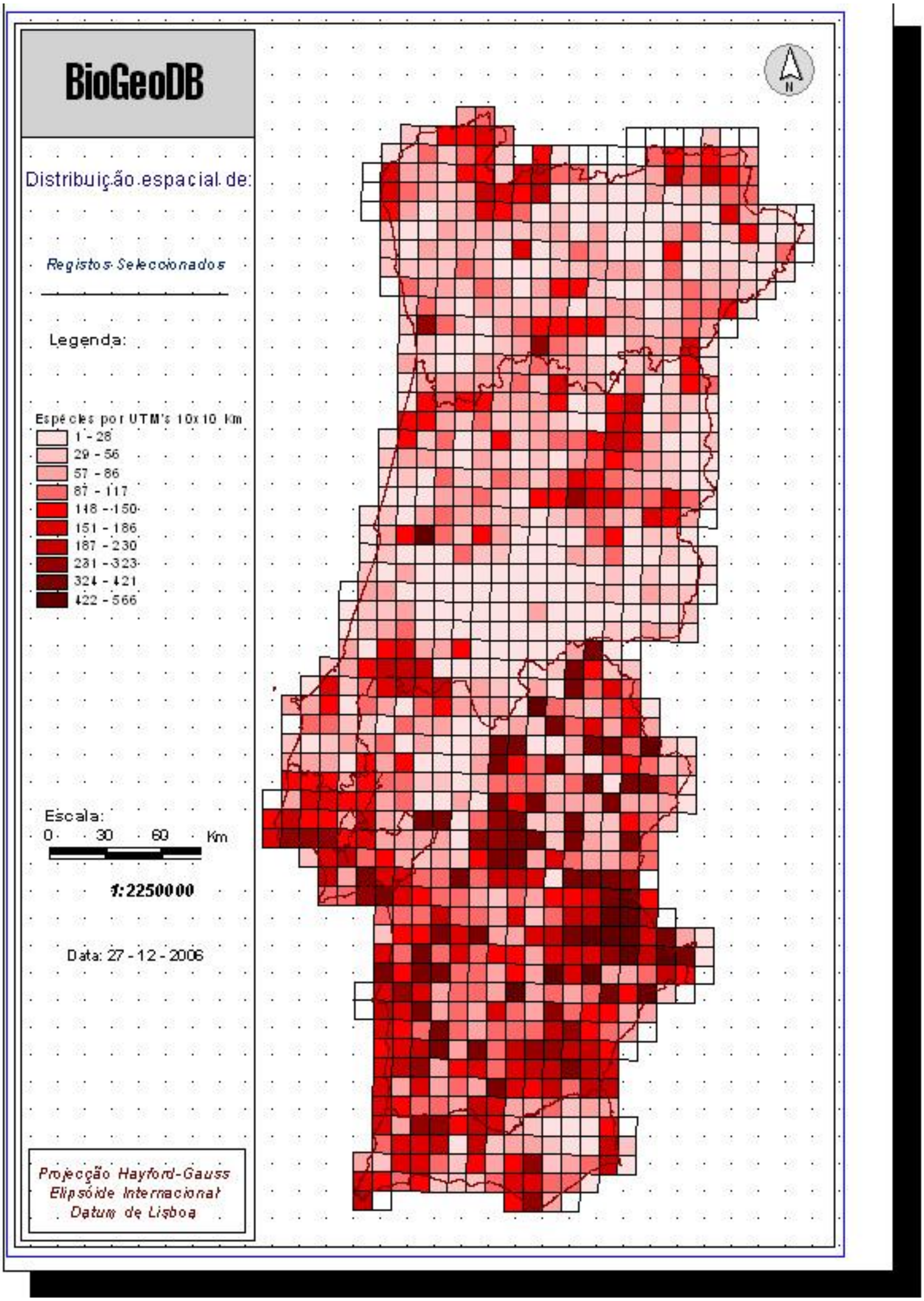

Figure 2-6. Count of species richness in UTM grid. The database reflects regional data sources with large number of species in Alentejo.

2.5 Discussion and conclusions

We appoint de simplicity and dedicated functions of the dual architecture as positive aspects. As a negative aspect we mention the retrieve process. This tool is a fundamental working instrument to the development of future studies.

The environmental issues become an imperative for life quality policies. Databases will therefore increasingly be part of environmental monitoring and the security of everyday life (Commission of the European Communities, 2005). The importance of computer science to biological knowledge is increasing; especially with spatial functions like species distribution. We have now new approaches for data analysis that otherwise would not be possible to perform, like satellite imagery instruments for spatial and temporal series. Either through remote control in local surveys, it will be necessary to make use of data to be able to act efficiently and to find fast answers during moments of crisis. With rigorous data structure it is possible to monitoring more efficiently the alterations that terrestrial ecosystems are subject to.

The potential of BioGeoDB is now starting to be explored, in analysis of temporal series by comparing historical records. We intend to make useful of application developed to perform planning decisions. BioGeoDB has potential for forthcoming projects providing sightings data The fact that a sufficiently homogeneous species dataset is provided, in comparison with other databases, allows us to state that it has enough quality for its use in biodiversity studies. In the future the decisive challenge will be to have summarized contents available on the Internet. The future goal will be therefore to create a platform that makes available its contents to the scientific community and the public, such as maps of distribution or species reports.

Acknowledgements

My acknowledgment goes to Pedro Roque and Rui Raimundo by them dedicated work on Avenue scripts and taxonomic issues and as a team members. To all dedicated UMC technicians and researchers by the support, especially Prof. Diogo Figueiredo. All team members of monitoring programs. The Funding support PORA, Sub-program C-Measure 2.

3 LARGE AREAS TRANSFORMATION

"This fragmentation of river ecosystems has undoubtedly resulted in a massive reduction in the number of species in the world's watersheds"
P. McCully (1998)

Abstract

The aim of this article is to describe the effects of the Alqueva dam reservoir on the Steppe bird's pattern distribution, measuring the bird's pattern before and after flooding using point-pattern analysis. To this end, we made use of sampling points from the dam biological monitoring program, which included data from winter and breeding seasons. To quantitatively assess spatial patterns, we tested the bird's point-pattern, applying a sequence of statistical methods. Autocorrelation was measured using Ripley's L-function and O-ring, and was validated by a complete spatial randomness null model in the bird's suitable habitat. A gradient surface of probabilistic abundance with Kernel Density Estimator was developed and compared with the Kappa Index of Agreement. The results indicate a decline in the absolute abundance of Steppe birds in both seasons, which is more evident in the breeding season. The results also show an increase in the mean distance between the point surveys, some evidence of a global trend towards the northeast direction, a decrease of patch values, and a disaggregation of continuous patches. The results were used to assess the effect of a dam disturbance on the Steppe bird's pattern distribution.

Keywords: Alqueva Dam, Monitoring, Point-Pattern Analysis, Pseudosteppes, Steppe Birds

3.1 Introduction

In recent decades, there has been growing interest in spatial issues, expressed by research in spatial pattern analyses (Perry et al., 2002). In most cases, the pattern of living species is related to the habitat or to a random selection over clumped patches (Lancaster & Downes, 2004).

The spatial pattern of species distribution is related to different ecological processes (Bergon et al., 2006). Understanding ecological processes starts with the identification of spatial patterns, spatial forces, and dynamic interactions (Legendre & Legendre, 1998; Davis et al., 2000; Fortin et al., 2002). In fact, spatial pattern discovery allows the testing of different underlying ecological processes and changes in recognizable structures.

The patterns themselves tend to be non-randomly located in space, as we expect from live individuals and communities as a sign of a regular modeling (Ebdon, 1985; Legendre, 1993; Perry et al., 2002; Bergon et al., 2006). Usually, living distributions exhibit a non-random configuration considering a spatial autocorrelation or dependency relationship (Bergon et al., 2006).

Spatial autocorrelation is a statistical property expressed by the similarity of values of a variable defining a spatial structure arrangement with no stochastic independence (Legendre, 1993). There are different sources of autocorrelation arising from space and time interactions, with direct implications for spatial patterns: True spatial autocorrelation comes from a direct interaction with a nearby occurrence, while induced spatial autocorrelation results from an indirect source affecting the dependent variable (Fortin et al., 2002).

The spatial structure of an ecosystem plays a key role in its dynamics (Goreaud & Pélissier, 2003), and spatial disturbance may result in different future evolution patterns. Natural and human disturbances can reshape communities and species distributions, such as in the case of dam construction; the consequences of a disturbance can therefore be tested and measured using sample data and spatial pattern analysis (Liebhold & Gurevitch, 2002).

Spatial pattern analysis is descriptive, based on assumptions and constraints, and its use characterizes distributions to help us formulate further hypotheses (Gatrell et al., 1996; Perry et al., 2002; Fortin et al., 2002; Wiegand & Moloney, 2004).

A possible way to measure the spatial patterns of living distributions is by using sampling points, which are easy to replicate in time and space (Davis et al., 2000). Point-referenced data are common in terrestrial ecology studies, and are referred to in statistics literature as ‘events’, or the position that a point occupies in relation to any other arbitrary point in the survey area (Gatrell et al., 1996).

Spatial point-pattern analysis involves local statistics and quantifies a pattern relative to nearby locations (Dale et al., 2002). It aims to assess the spatial pattern based on the individual point distribution and to establish a relationship with the underlying mechanisms of the observed pattern (Legendre, 1993). A common way to identify the underlying mechanisms is to test properties of a point-pattern against a random process (Goreaud & Pélissier, 2003).

There are many possible questions related to spatial positions and different ecological process, e.g. facilitation or competition (Wiegand & Moloney, 2004). In many instances, the purpose is not only to measure the density of the points in three possible patterns - aggregation, regular, and random - but also other properties, e.g. bearing directions (Fortin et al., 2002). Points in a point-pattern may contain information other than the three patterns, and can be referred as a ‘metapattern’, e.g. a species identifier or life stage.

A wealth of spatial point-pattern analysis applications exist in ecology studies, mainly in plant ecology (Goreaud & Pélissier, 2003; Wiegand et al., 2006; Atkinson et al., 2007), but also in a variety of other subjects (Gatrell et al., 1996; Davis et al., 2000; Khaemba, 2001; Lancaster & Downes, 2004; Bishop ,2007; Vasudevan et al., 2007; Fisher et al., 2007). In our study, we use spatial point-pattern analysis to determine the effects of the Alqueva dam reservoir on the Steppe bird’s spatial pattern.

According to Telleria (1988), studies on Steppe birds should include spatial and temporal variations, as these are aspects of utmost importance for population dynamics. Generally, studies on population dynamics assess spatial tendencies using grid squares methods. Nevertheless, little attention has been paid to the role played by point-pattern analyses (Fisher et al., 2007) in assessing spatial patterns. Spatial point-pattern analysis can, thus, be a complementary method, helping us to detect variations and trends in pattern dynamics, which is a significant way to identify environmental interactions with the species' distribution.

Most spatial distribution impacts on species are related to the human action of land cover changes (Theobald et al., 2000). Large dams enormously affect the local ecology (McCully, 1998), with huge, complex, and multivariate impacts on the ecosystem (Berkamp et al., 2000). The Alqueva dam, which is being built in the south of Portugal, flooded an area of 25,000ha, wherein habitat loss and fragmentation displaced many wildlife species, while at the same time attracted other species to the new habitats. The flooded areas affect the habitats of several species. Our case study is based on Steppe birds, this group of species are focus of special attention due to here unfavorable conservation status, as referenced by BirdLife International (2004).

3.2 Case study

In this study, we consider spatial point-pattern analysis as a way to answer our question: How has the Alqueva reservoir affected the Steppe bird's spatial patterns? To this end, we tested the following:

a) Whether there was a spatial arrangement of the point-pattern before (T_0) dam construction:

    i. using all distribution point surveys, against

ii. the modeling scenario (without the points inside the future maximum water line).

b) Whether there was a spatial arrangement of the point-pattern before the dam against the observed pattern after (T_1) dam construction.

The first test aims to validate and ensure the existence of a pre dam pattern, the second test aims to identify the disturbance case by the reservoir in the Steppe birds distribution. We do not aim to describe composition aspects, life-stages, or demographic dynamics; our purpose is simply to test the point distribution surveys with a sequence of statistical methods to quantify point-pattern changes and infer effects of reservoir.

It should be noticed that the list of Steppe bird species presented in this article (Table 3-1) is broad because it is based on the use of habitat. The list contains eight distinct species in assemblages of six each season: four resident species, with two exclusive breeding species and two exclusive winter birds.

Table 3-1. Steppe Birds Assemblage List and Conservation Status

Specie name	Common name	Category (2004)	Fenology
Burhinus oedicnemus	Eurasian Thick-knee	SPEC 3	Resident
Coracias garrulous	European Roller	SPEC 2	Breeding
Glareola pratincola	Collared Pratincole	SPEC 3	Breeding
Otis tarda	Great Bustard	SPEC 1	Resident
Grus grus	Common Crane	SPEC 3	Winter bird
Pluvialis apricaria	Eurasian Golden-plover	Non-SPEC	Winter bird
Pterocles orientalis	Black-bellied Sand grouse	SPEC 3	Resident
Tetrax tetrax	Little Bustard	SPEC 1	Resident

The data were obtained from the biological monitoring program contracted by dam's owner, which also surveys other biological groups (Pereira, 2008). In the case of the Steppe bird, the census period ranged from before the dam's flooding (1999-2000) to after (2002-2003), and was conducted in the winter (Ws) and breeding (Bs) seasons. The monitoring surveys were carried out on a 176,000ha of the dam region, represented by 11 maps. The survey area was subdivided in tessellations of a 1km contiguous grid and the data were collected along linear transects, defined to pass overall grids, in order to guarantee the same field efforts cover. The survey was conducted following standard methods of field observation: a 10-minute stop at each point, with all species seen or heard identified and recorded (Howe et al., 1997). Census data were referenced by point-spaced (discrete) location and attribute(s) like species name, species abundance, and date. A GIS project was developed to manage all survey and land cover data (Pereira, 2002).

3.2.1 Study Area

The study region is delimited by parallels 38º05'00 and 38º50'00 North latitude, and meridians 7º40'00, 7º10'00 West longitude (Figure 3-1).

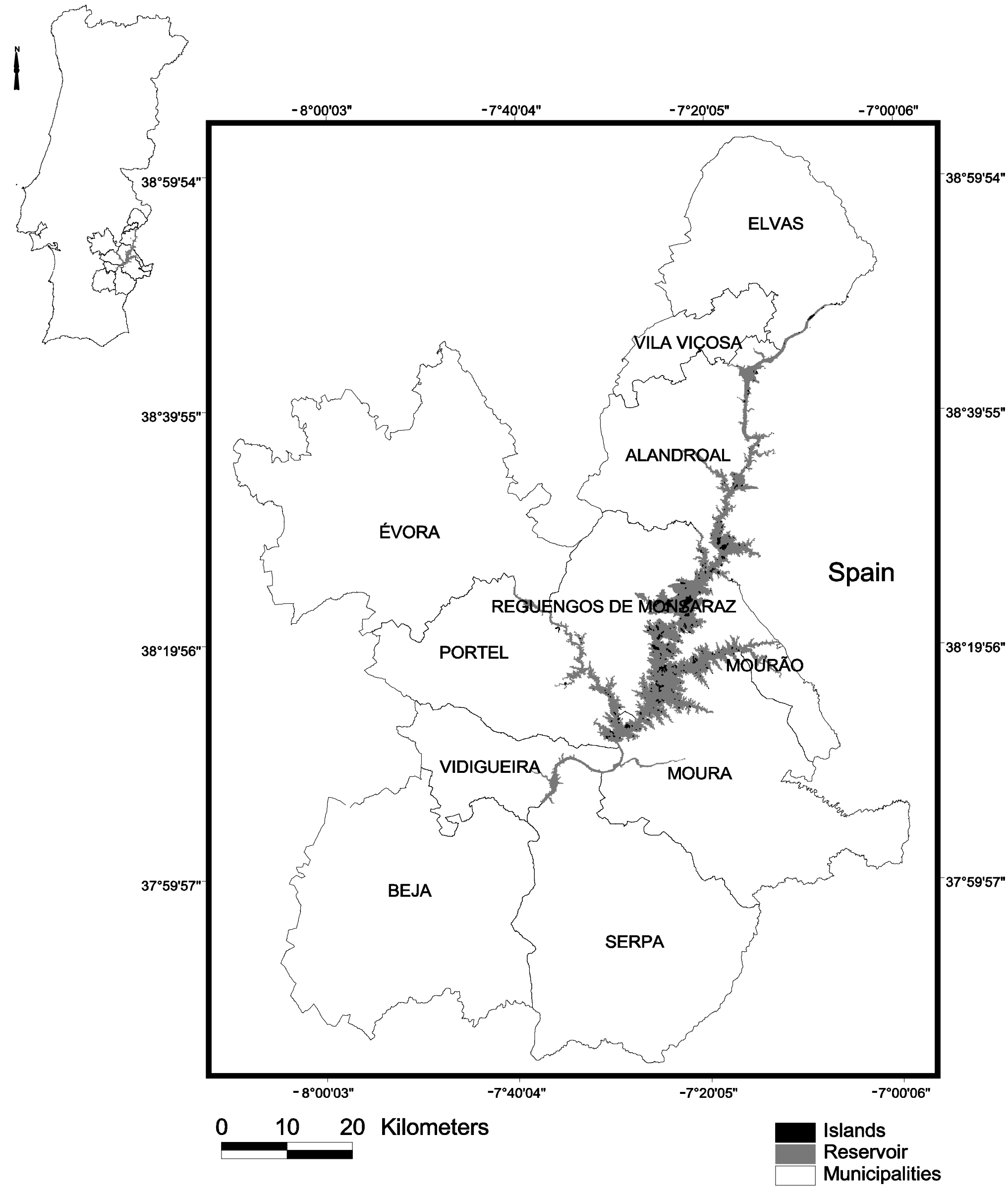

Figure 3-1. Alqueva dam's within national and regional context; regional municipalities are mainly in Central Alentejo III level EUROSTAT nomenclature territorial units for statistical purposes (NUTS).

Alqueva Dam is located at the Guadiana River in the Alentejo region of Portugal's mainland. The dam is Portugal's and Western Europe's largest, covering a surface area of 25,230ha (24,160ha in Alqueva and 1,070ha in Pedrógão), and its straight-line length is around 100km. Alqueva collects direct runoff from a 10,648km^2 catchment area, 5,800km^2 in Portugal and 4,848km^2 in Spain (POAAP 2000), and its maximum fill capacity is 152m above sea level.

The landscape morphology is marked by a flat plain (100–300m) and the climate is Mediterranean, with hot dry summers (an average daily of 35ºC in July), cool winters (averaging 5ºC in January), and 500-600m of rainfall between October-March, during which about 75% of annual rainfall occurs. The habitat land cover is a mosaic, dominated by Holm oaks (*Quercus Rotundifolia)* and Cork oaks (*Quercus suber)* in woodlands of variable tree cover density, frequently with a grassy area under storey grazed by livestock, or by Savannah-Pseudosteppes areas (Pinto-Correia, 2000).

The Steppe bird's habitat is dominated by Pseudosteppes and dispersed Cork/Holm oaks marked by a mosaic of cereal crops. Steppe birds are related to land field agriculture management. Usually the land field management is conducted in 3-5 uncultivated fallow years in a rotation cycle management: 30% to 80% of the land is left fallow each year (Suárez et al., 1997). The recent trends in land cover change in this Portuguese region have effects on the Pseudosteppes habitat. The intensification of agriculture will consequently provoke a loss of fallow land, which will have a negative influence upon species of Steppe birds (Delgado & Moreira, 2000; Stoate et al., 2001; Faria & Rabaça, 2004; Moreira et al., 2005; Moreira & Russo, 2007). The Steppe bird's distribution is associated with rainfall in the breeding season and temperature in the winter. Although this relation is not deterministic, it is associated with the food regime (Telleria et al., 1988), which is composed of grain seeds and insects available in the open land of farming areas.

3.3 Applied methods

The selection of feasible methods for the identification of spatial patterns is dependent on two main purposes: (a) the research objective, and (b) measurement types of sampling designs (Ebdon, 1985; Fortin et al., 2002). To this end, we apply the statistical methods step-by-step as illustrated in the working sequence. In the next section, we briefly describe the statistical methods, while for more detailed information we encourage consulting the referenced authors. The analysis starts with dispersion measures as a way to describe the trends and define the homogeneous region of the point distribution.

3.3.1 Dispersion Measures

Standard Deviational Ellipse (SDE) was used as a dispersion measure around the mean center to evaluate the orientation trend (Anselin, 2003) and reduce outliers. This was a straightforward method to reduce the processing data to the essential data on the bird's core area distribution. SDE involves centrography, referenced on the mean centre, which can be calculated with a weight factor (Ebdon, 1985).

In our case study, the SDE was calculated for two standard deviations corresponding to 95% of event frequency (Figure 3-2). In the SDE calculation, we define the weight factor value of individual abundance in each point. The weight factor allows us to consider the weight centre according to the number of recorder individuals. From the resulting drawn ellipse we achieved the trend direction and the selection of a homogeneous area of bird survey, encompassing a sub-region of $\approx 56\,000 ha$ (Figure 3-3). To execute the SDE process, we used analysis tools for ArcGIS 9.1 ESRI software.

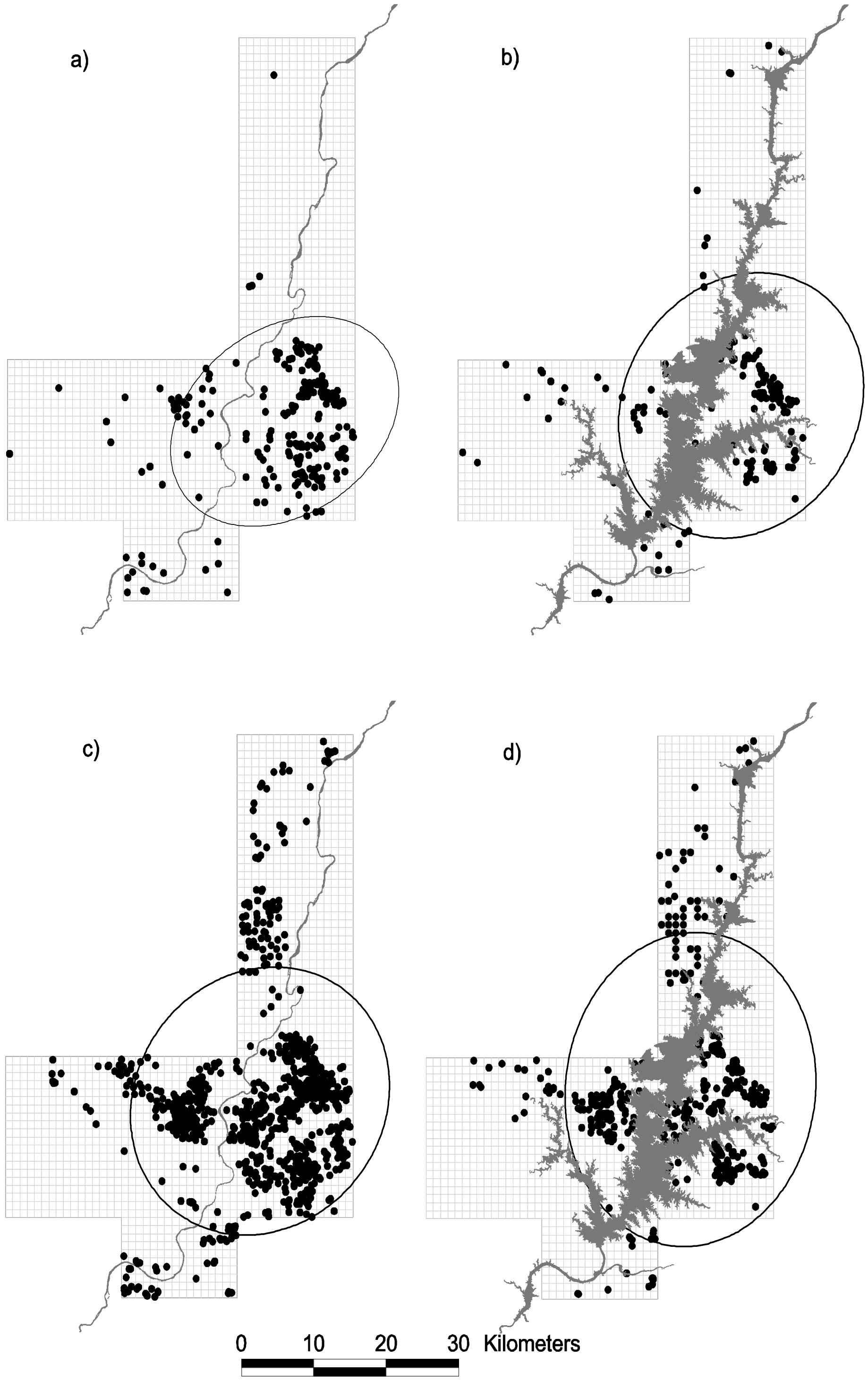

Figure 3-2. Point spread during the two periods of field sampling in 1km grid square, grey line represents the main river before and after the dam water shape. a) weighted SDE in the winter season T_0. b) weighted SDE in the winter season T_1 there is a ellipse rotation to North (12 deg) in birds trend. c) weighted SDE in the breeding season T_0. d) weighted SDE in the breeding season T_1 there is a ellipse rotation to North (49 deg) in birds trend.

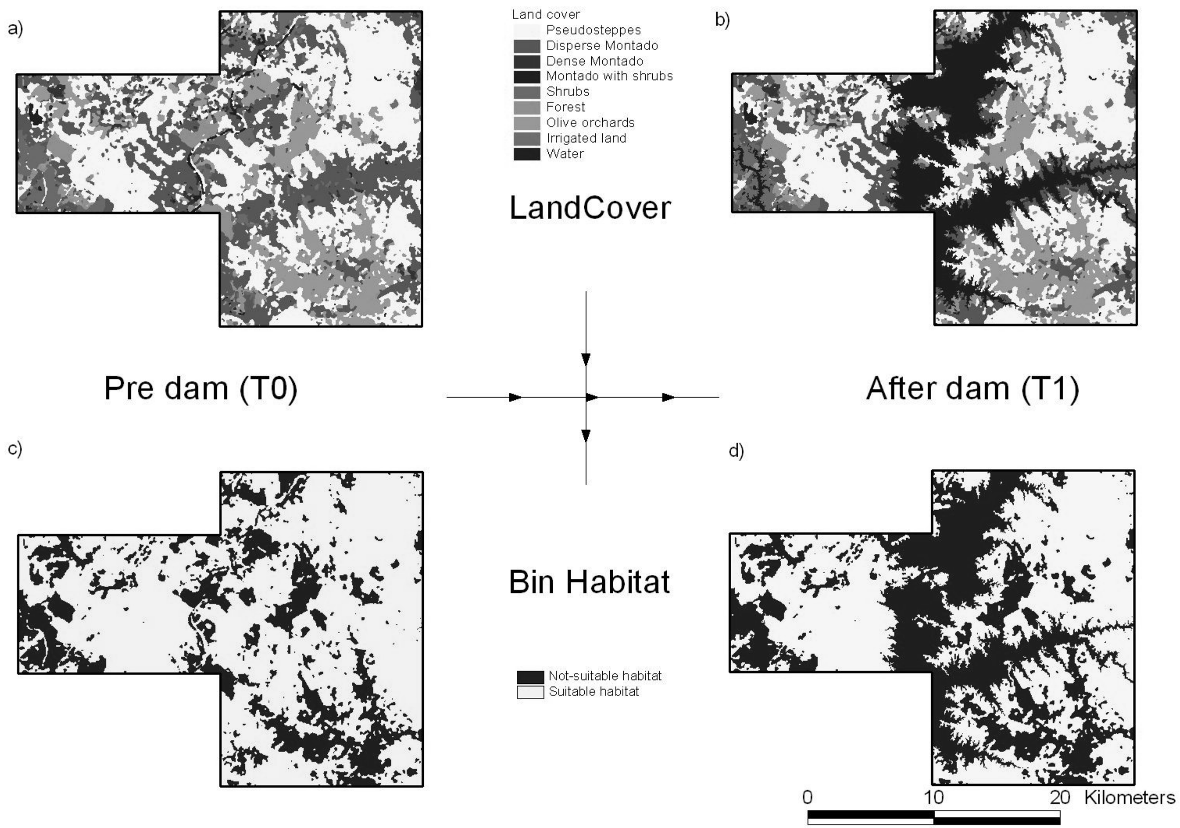

Figure 3-3. In this study area the habitat of Steppe birds was significant reduce: a) nineth class in T_0 period; b) nineth class in T_1; c) binary reclassification of habitat classes in T_0 period; d) binary reclassification of habitat classes in T_1.

3.3.2 Remote Sensing

In order to identify the suitable habitat of Steppe birds, we used a land cover classification, generated by supervised classification and resampling to a 25m resolution (Thomas et al., 1995). The images were taken by the Landsat 5 TM satellite in July 1997 and by the Landsat 7 ETM+ in August 2001.

The study area presents heterogeneous habitat conditions that were taken into consideration in the spatial analyses. The result was a nine-class legend habitat map defined as follows:

> 1-Pseudosteppes; 2-Disperse Cork/Holm oaks; 3-Dense Cork/Holm oaks; 4-Cork/Holm oak with shrubs; 5-Shrubslands; 6-Forest (*Pinus* spp. and *Eucalyptus* spp.); 7-Olive orchards; 8-Irrigated land; 9-Water.

The land cover classification was then reclassified in terms of a binary class habitat of suitable/non-suitable (Figure 3-3) for Steppe birds. The suitable habitat class was defined by the first two classes above (Pseudosteppes and Disperse Cork/Holm oaks). Eighty-five percent of the individual Steppe birds were observed in these two classes, while the other classes defined as non-suitable habitat comprise the remaining birds. Image classification and resampling were performed using Idrisi 32 Clark software.

3.3.3 Intensity Measures

We were very interested in the confidence test of first and second-order properties in order to detect how the expected average of the point-pattern process changes along the extent area and the co-occurrences of pairs of points. The point-pattern behavior can be due to trends in first or second-order property variation from correlation structures (Dungan et al., 2002). In many real data sets, the two properties may be conjugated and mixed. We used Ripley's *K*-function and *O*-ring to identify the first and second-order properties of points in the study area (Wiegand et al., 2006). These methods are important for identifying the bird's density and detecting changes in autocorrelations of spatial patterns. These methods enable us to understand how the pattern of the points acts within the circle and at the distance of the ring.

Ripley's *K*-function is an intensity measure of the cumulative count of points in concentric circles (buffer), centred around an arbitrary event and divided by the intensity λ of the distribution (Ripley, 1976; Wiegand & Moloney, 2004; Goodchild & Haining, 2004). Ripley's *K*-function is accessed by the square root transformation of the *L*-function that linearizes and stabilizes the variances (Fortin et al., 2002; Lancaster & Downes, 2004).

Wiegand & Moloney (2004) suggest an *O*-ring measure as the intensity of a pair correlation λ function (or a conditioned probability spectrum, Galiano, 1982), which is defined by the count of events touched by the rings of a defined distance (d), centred around an arbitrary event and divided by the intensity λ of the distribution.

The implementation of geometric concentric circles and rings in spatial statistics usually requires edge effect corrections as an unbiased outside area measure. This affects the estimated strength of the process under analysis, due to fewer samples along the border in comparison with the middle of the extent area. To avoid this bias, a numerical approach was used to correct edge effects, where a grid cell tessellation adjusts to the extent area (Wiegand & Moloney, 2004). This method implements faster processing performance with increased flexibility analysis by ignoring proceedings in outside areas. Ripley's *L-function* and *O*-ring analysis were performed with the use of *Programita* application (Wiegand & Moloney, 2004).

We defined a concentric increment of 1 grid cell (25m) in a maximum of 100 cells with a radius of 2,500m to maximum circus. We define 2,500m as the maximum radius base on two assumptions: a) threshold distance of species' local movements, as indicated by experts; and b) to avoid processing resources in edge effect corrections of the extent area. In order to test our hypotheses, we generate a complete random selection (CRS) and compare it with the observations. To reduce the chance of Type I error, a random 999+1 replicate was generated for confidence limits with a significance level (*P* 0.001) using the 5% upper and 5% lower bounds goodness-of-fit test (Baddeley et al., 2005). The CRS was constrained in the suitable habitat, which is justified by the fact that the probabilities of individual occurrences outside were low.

3.3.4 Kernel Density Estimator

Kernel density estimation is commonly used in home range analysis, and was used in the current study to estimate the 'population' or reconstruct the distribution from sampling points (Brunsdon, 1995; Fotheringham et al., 2002; Heinz & Seeger, 2006). Roughly speaking, we could consider the explicit surface of a histogram from the frequency distribution of an (z) attribute (Fotheringham et al., 2002). KDE is a nonparametric approach with no assumptions (*the data speak strictly for themselves*). It is a solution to estimate general probability densities based on discrete sampling, as was our case.

We were very interest in reconstructing the distribution and passing from discrete sampling to continuous surface. This process allows us to identify two main proposes: a) hot spots of bird's distributions and b) to obtain a measurable continuum surface that could be compared subsequently. To simplify the analysis it was established four classes between Low-Low to High-High densities and a void class (without birds).

The smoothing factor (usually known as bandwidth or h statistics) defines the surface of kernel density estimate. In our case study, the gradient of abundance value probability (KDE function) was performed in 500 m bandwidth. The choice of bandwidth distance was an approach decision taken in the research process. It was only after some tests of different *h* that the value of 500m was defined, most based on mean distance points. To execute the KDE process, we used Hawth's analysis tools for ArcGIS ESRI software (Beyer 2004).

3.3.5 Contingency Analysis

The sequence work of the KDE output maps was analyzed with the help of a contingency table technique. Cross tabulation allows the evaluation of the data matrix (maps) of equal size and resolution, usually in categorical variables. Cross tabulation is useful in the research of interaction moments in order to compare relationships in a simple table, with the output expressed in a contingency table, representing the dynamics of the two moments.

Kappa Index Agreement (KIA) can be used in order to analyze the concordances and to consider the correction for chance in the agreement. We used KIA based on the fact that is an overall and per-class index (Cohen 1986). It ranks from a value of -1 to a value of 1, and validated in a test of chance (Visser & De Nijs, 2006). Landis and Koch (1977) presented interpretative categories for KIA, from 'no agreement' to 'almost perfect agreement'. The contingency table analysis (cross tabulation) and KIA index calculations were performing using Idrisi 32 Clark software.

3.4 Results

The first, and probably most significant, result is shown in the descriptive statistics (Table 3-2). Steppe birds show a substantial decrease of abundance after the dam's construction, with consequences in spatial patterns. In fact, the reduction of overall abundance values observed inside SDE shows a loss of 36% in the winter and 74% in the breeding season. As for their average abundance at each point, there are contradictory directions, with increasing mean values in the winter and decreasing mean values in the breeding seasons. The maximum values of abundance are related to large groups of birds and also decrease substantially. Index of Dispersion (ID) clearly defines a situation of aggregation abundance in the two periods in both seasons. The results of the nearest-neighbor (NN) show an increased mean distance within inter-points after construction of the dam.

Table 3-2. Descriptive Statistics and Dispersion Index

Statistics	$T_0(W_s)$	$T_1(W_s)$	T_0M_s (W_s)	$T_0(B_s)$	$T_1(B_s)$	T_0M_s (B_s)
Events (*n*)	241	118	222	909	349	834
Sum (abundance)	7407	4743	6344	2117	561	2026
Max (abundance)	650	600	400	120	30	120
Average (abundance)	30.73	40.19	28.58	2.33	1.60	2.43
Standard deviation	68.38	86.15	56.63	5.75	2.34	5.99
Index of dispersion (ID)	152.17	184.67	112.21	14.18	3.45	14.76
NNeighbour (mean distance)	501.11	669.21	477.55	280.76	402.08	275.35

T_0=Before dam; T_1=After dam; M_s= Modeling scenario; W_s=Winter season; B_s=Breeding season.

From the fitting SDE, we were able to verify a change in the core area of the bird survey, with an evident extending movement after the dam's construction (Figure 2). The measures trend of point-pattern change was in the *NE/SW* direction. The weighted mean center of the point-pattern changes the location towards East $\approx$850m and North $\approx$2,000m in the winter season. The change in position was also evident in the breeding season towards East $\approx$1,350m and North $\approx$1,600m. If we consider the Euclidean distance the center change $\approx$2,175m in winter and $\approx$2,100m in the breeding season to the Northeast direction.

The output maps on land cover class reclassification were our cartographic support for the Steppe bird's habitat identification. The resulting map was overlaid with the shape of the dam's flooding level, enabling us to model an isotropic and constraint space of the suitable habitat (Pommerening & Stoyan, 2006). Considering the core area (Figure 3), the impacts of flooding reduced the suitability of the habitat by 22% in the land cover changes (Table 3-3).

Table 3-3. Binary Class Habitat Transference Between T_0 and T_1 Periods

Habitat	T_0	T_1	T_0-T_1
Suitable	41136*ha*	32282*ha*	-22%
Not-suitable	14865*ha*	23719*ha*	+59%

Before dam construction, Ripley's *L*-function shows a well-defined spatial aggregated point-pattern. The results clearly identify a high aggregation of points along the survey area in the winter (Figure 4a) and breeding seasons (Figure 5a). The results of the model scenario confirm the existence of a well-defined point-pattern distribution. The point-pattern is still stable and coincident in all distances between the two analysis situations (Figure 4a-b). The results of the *O*-ring are coincident with Ripley's *L*-function in the breeding season but not in the winter. In the breeding season, *O*-ring detected well-defined aggregation within almost all distances (Figure 7a-b) and an undefined spatial point-pattern in the winter season (Figure 6a-b).

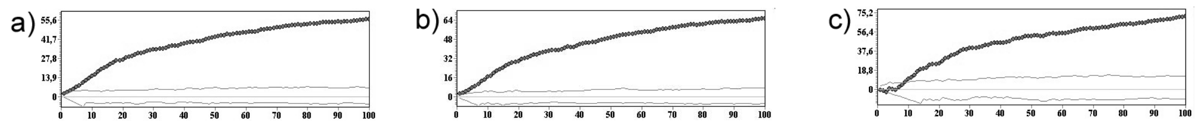

Figure 3-4. Ripley's *L*-function the winter season (*P* 0.001). a) T_0 Point-pattern shows a well-defined aggregation from near distance up to 50m. b) T_0M_s Point-pattern keeps the same aggregation of T_0 in every measure distance up to 50m. c) T_1 Point-pattern shows a clear random distribution in the short distances, up to 225m.

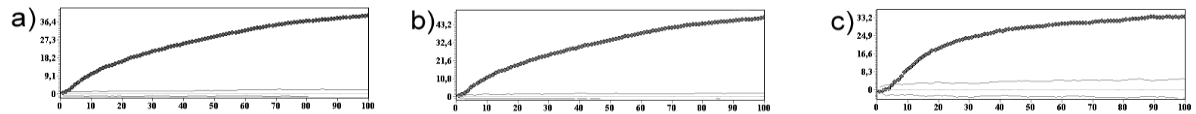

Figure 3-5. Ripley's *L*-function in the breeding season (*P* 0.001). a) T_0 Point-pattern shows a well-defined aggregated from near distance up to 25m. b) T_0 M_s Point-pattern keeps the same aggregation behavior of T_0 in every measure distance up to 25m. c) T_1 Point-pattern shows a clear random distribution in the short distances, up to 125m

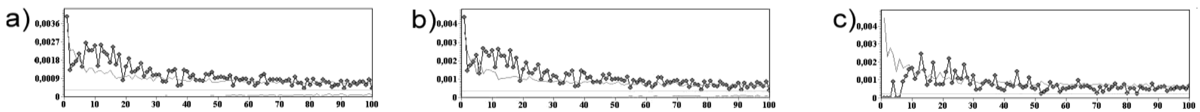

Figure 3-6. *O*-ring in the winter season (*P* 0.001). a) T_0 Point-pattern shows an undefined behavior. b) T_0 M_s Point-pattern shows an undefined behavior. c) T_1 Point-pattern shows an undefined behavior.

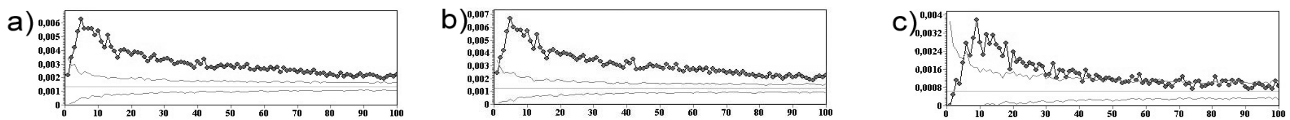

Figure 3-7. *O*-ring in the breeding season (*P* 0.001). a) T_0 Point-pattern shows a well-defined aggregated behavior from almost distance. b) T_0 M_s Point-pattern shows a well-defined aggregated behaviour from almost distance. c) T_1 Point-pattern shows a random behavior at short and long distance.

The autocorrelation of the point-pattern decreased substantially after the dam's construction. When we look at the results of Ripley's *L*-function and *O*-ring after the dam's construction, the points start to show a clear perturbation (random) in both seasons. Ripley's *L*-function of point-pattern shows random behavior, well evident in short distances up to 225m *r* in winter (Figure 4c) and 150m *r* in breeding seasons (Figure 5c). The *O*-ring of the point-pattern in the winter and breeding seasons is increasing and unstable within most distances (Figure 6c-7c).

The KDE map before dam construction in the winter season clearly reveals the existence of three main patches of bird areas, with different shape configurations and density gradients (Figure 8a). In the breeding season, the map shows the existence of five main patches (Figure 9a). After the dam's construction, the results showed desegregation of continuous patches, with spatial polarization of species abundance and a substantial reduction of gaps in the bird's densities (Figure 8b-9b).

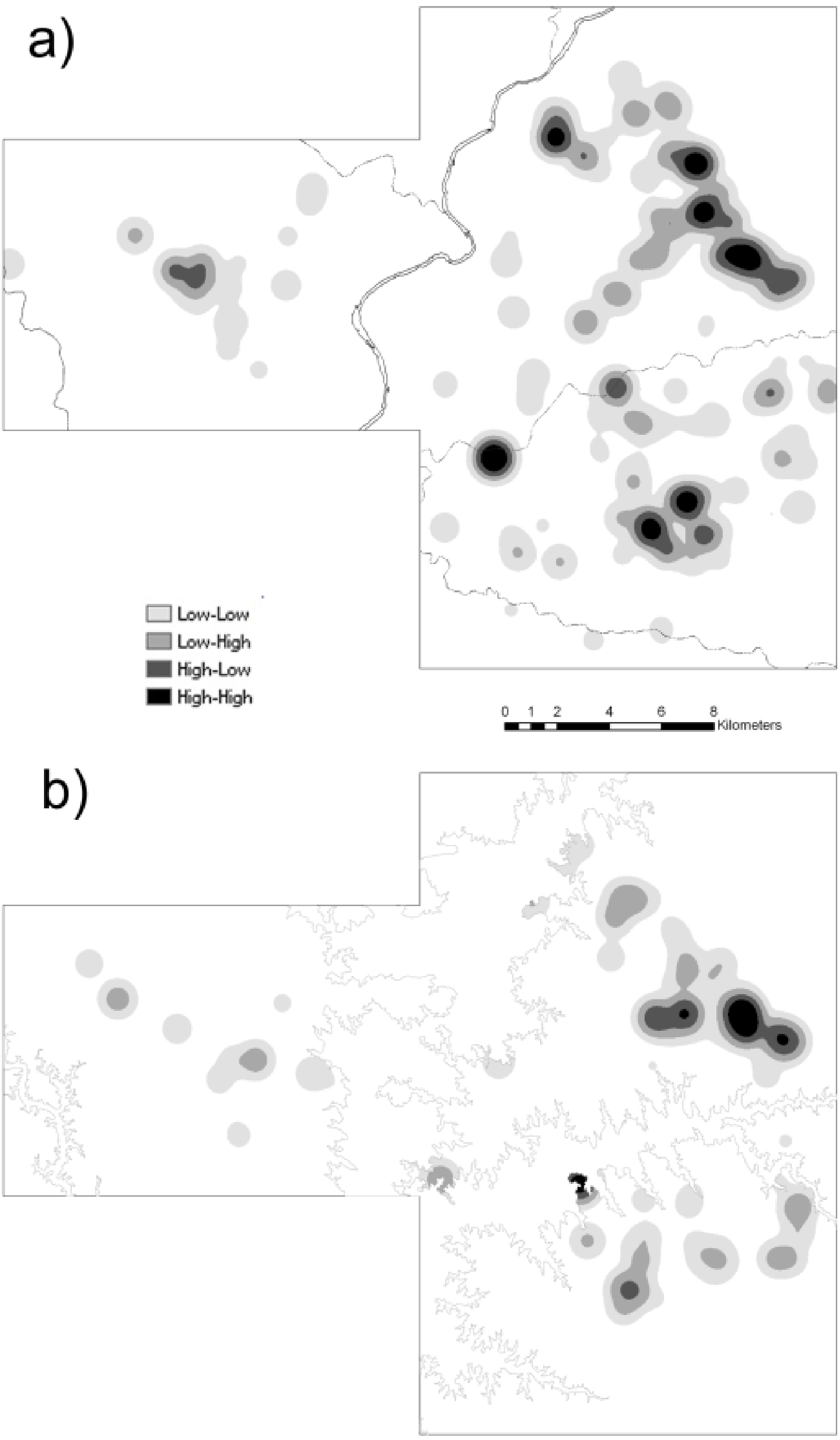

Figure 3-8. KDE of reshaped map for 95% of the bird winter season population in four classes of densities a) in T_0, the solid line represents the main river and the dash lines the secondary rivers; b) in T_1, the solid line represents the flooding water level.

The KIA was computed to compare overall and per-class area before and after dam construction. The results of overall area indicated an KIA index of 0.285 in the winter season and 0.378 in the breeding season, which means there is fair agreement before and after dam construction. Looking at the results of the KIA in the winter season based on per-class density highlights three situations:

a) Void class (0.531)-Moderate agreement;
b) High-High class (0.203)-Fair agreement;
c) Low-Low class (0.163), Low-High (0.111) and High-Low (0.128)-Poor agreement.

In the breeding season, the results highlight a different arrangement:

d) Void class (0.685)-Substantial agreement;
e) Low-High class (0.217), High-Low (0.218) and High-High (0.203)-Fair agreement;
f) Low-Low class (0.191)-Poor agreement.

The contingency tables show the transferences between classes, and the diagonal of the tables represents the unalterable density area (in percentage) for each class of densities (Table 3-4 and Table 3-5). The contingency analysis in the winter map reveals that the void class increased after dam construction in both seasons. The area transference is significant in the winter, the void class of birds kept 75.2% of its area and increased 7.6% (Figure 8b), and in the breeding season kept 53.5% of the area and increased 10.6% (Figure 9b). These results indicate that the loss of area of classes goes to void, representing a loss of space occupied by different bird species.

Table 3-4. Proportional Contingency Tabulation of Winter Season (W_s) in T_0 Against T_1 Periods

	Void	Low-Low	Low-High	High-Low	High-High	T_1
Void	75,27%	8,96%	2,42%	0,81%	0,35%	**87,82%**
Low-Low	3,83%	2,73%	1,08%	0,45%	0,18%	**8,27%**
Low-High	0,87%	1,01%	0,56%	0,22%	0,05%	**2,71%**
High-Low	0,15%	0,16%	0,28%	0,24%	0,03%	**0,86%**
High-High	0,06%	0,02%	0,02%	0,08%	0,16%	**0,34%**
T_0	**80,19%**	**12,88%**	**4,37%**	**1,80%**	**0,76%**	100%

Table 3-5. Proportional Contingency Tabulation of Breeding Season (B_s) in T_0 Against T_1 Periods

	Void	Low-Low	Low-High	High-Low	High-High	T_1
Void	53,53%	14,56%	2,38%	0,21%	0,09%	**70,77%**
Low-Low	5,35%	7,38%	3,01%	0,81%	0,16%	**16,72%**
Low-High	1,08%	3,02%	2,35%	1,24%	0,44%	**8,13%**
High-Low	0,21%	0,83%	0,92%	0,83%	0,52%	**3,30%**
High-High	0,00%	0,04%	0,32%	0,41%	0,32%	**1,08%**
T_0	**60,17%**	**25,83%**	**8,98%**	**3,50%**	**1,53%**	**100%**

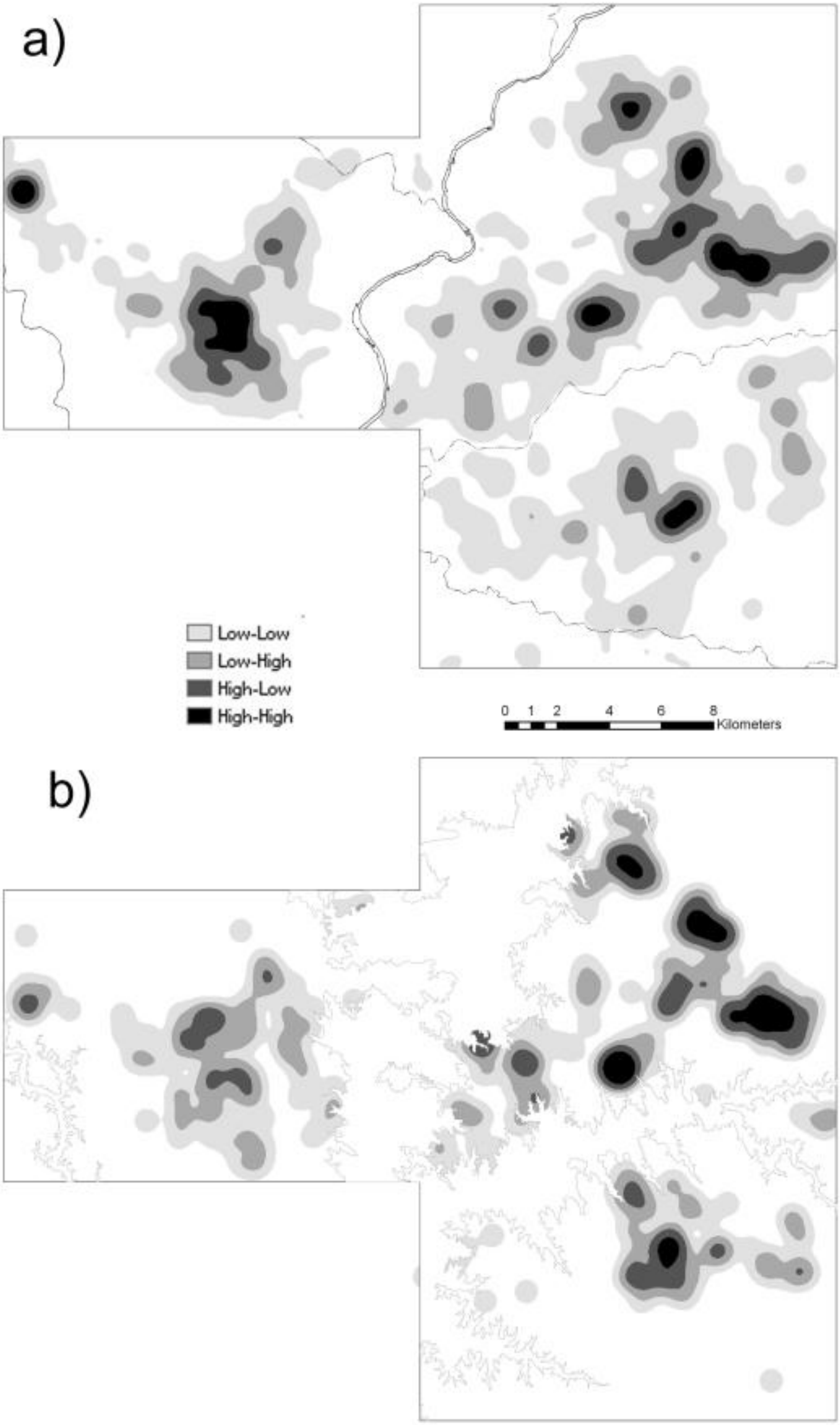

Figure 3-9. KDE of reshape map for 95% of the birds breeding season population in four classes of densities a) in T_0, the solid line represents the main river and the dash lines the secondary rivers; in b) T_1, the solid line represents flooding water level.

3.5 Discussion and conclusions

In this article, we describe a test for measuring the effects of a flooding reservoir on Steppe birds that is based on spatial point-pattern analysis. The results show that the adopted methods provide useful statistics on local monitoring data. We demonstrate the relevance of spatial point-pattern analysis in bird surveys, and show how spatial data can be useful for identifying the reservoir disturbances.

Although spatial analysis reveals an identified pattern, it is usually an empirical approach based on observational data. It is, therefore, always prudent to take into consideration other components of the process, which can be assessed by other types of analyses and models of local bird distributions (Dale et al., 2002). We are aware that the results of a pattern may result from different sources of processes (Perry et al., 2002; Wiegand & Moloney, 2004). If a null model describes the pattern well, it is not appropriate to conclude that the mechanism behind it is the mechanism responsible for this particular observed pattern (Gatrell et al., 1996; Perry et al., 2002; Wiegand & Moloney, 2004). Inferring the underlying process from a point-pattern analysis may involve subjective judgements (Gatrell et al., 1996).

As more point data become available, more accurate patterns of species will be revealed to test environmental changes. The point-pattern of species distribution can be a predictor of environmental change. Using discrete data maintains the source pattern, and also identifies the 'metapattern' or a fingerprint of the data collection. Monitoring programs generally include the knowledge of the number of species (richness) and individuals (abundance), and pattern analysis in quadrats. Aggregate data tend to develop erroneous inferences, like ecological fallacy, in bottom-down destruction processes, reducing the unit variation of individuals and increasing the homogeneity of the group (Clark & Hosking, 1986).

The applied methods helped us to characterize first and second-order properties, and proved to be an effective choice for measuring the point-pattern. Their combination was especially helpful in the archived results. As no single method can reveal all properties of spatial data, complementary ones may highlight some important characteristics. Their combined use gave us the opportunity to relate the spatial pattern and the ecological processes of dam construction. We are aware that these methods are not new, but are still useful, depending on whether they are reused in a proper way.

In our case study there was statistical evidence to conclude that: a) the point-pattern of Steppe birds before the dam's construction was not random; b) manifest disturbances after the dam's construction are more evident in the near distances between points. The Steppe birds seem to have reacted to the dam's development with an overall decreasing abundance, mainly in the breeding season.

From the archived results we conclude that the applied methods are good tools for recognizing and quantifying the pattern dynamics. The increased NN distance is probably evidence of individuals' erratic behaviors. The application of SDE was useful for reducing the 'noise effects' of outliers by defining the homogeneous sub-region (Goreaud & Pélissier, 2003). There is indication of a global trend towards the northeast. The new centre of weight abundance seems to indicate a change in the local pattern distribution of all Steppe birds. The observed trend could be explained as a pattern adjustment in the *NE/SW* direction as a result of the elongated configuration of the reservoir (Figure 2).

Ripley's *L*-function and *O*-ring provided not only measures of distribution up to a certain distance, but also information about autocorrelation at the defined distance. Ripley *L*-function was a good measure of point aggregation, before and after dam construction, and *O*-ring was a good measure of point behavior in the winter and breeding seasons. *O*-ring is a good complementary measure not often used in ecological studies (Lancaster & Downes, 2004).

The results of the KDE map in winter and breeding seasons show a considerable decrease in spatial densities after the dam's construction. If we consider the point density, we see that there was a clear overall spatial reduction of the patch size and a lack of continuity as a consequence of habitat loss and fragmentation. The overall spatial reduction was expressed by an increased multi-disaggregation of the large patch of bird densities. Nevertheless, the point-pattern was much more defined and spread out in the breeding season, a fact that might be explained by the nesting occurrence of couples of birds that use more space.

It is possible to understand and assess the function of the rivers and the implications of reservoir development in the ecological process with data and continuity monitoring (King & Brown, 2000). The preservation of resources and the affected values depend on our capacity to develop plans and actions that improve decision processes.

To quantitatively assess the long-term patterns of Steppe birds, monitoring data is needed to make a comparison with this study. The reservoir effects should be seen in global, the direct effects by construction disturbance and indirectly by the new roads and traffic expected by the new functions (i.e. touristic activities). The assumptions that dam construction has a disturbance effect on Steppe bird patterns are somewhat obvious, but until know the measurement evidence was not performed using quantified reports of point-pattern analysis.

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4 LINEAR INFRASTRUCTURES IMPACTS

"*Humans have spread an enormous net over the land*" R. Forman (2003)

Abstract

Research of habitat fragmentation has revealed a large number of constraining effects on species, which 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 development and suggestions for defragmentation actions.

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

4.1 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.

4.2 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).

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.

4.3 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 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).

4.3.1 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.

4.3.2 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 4-1). 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 m 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.

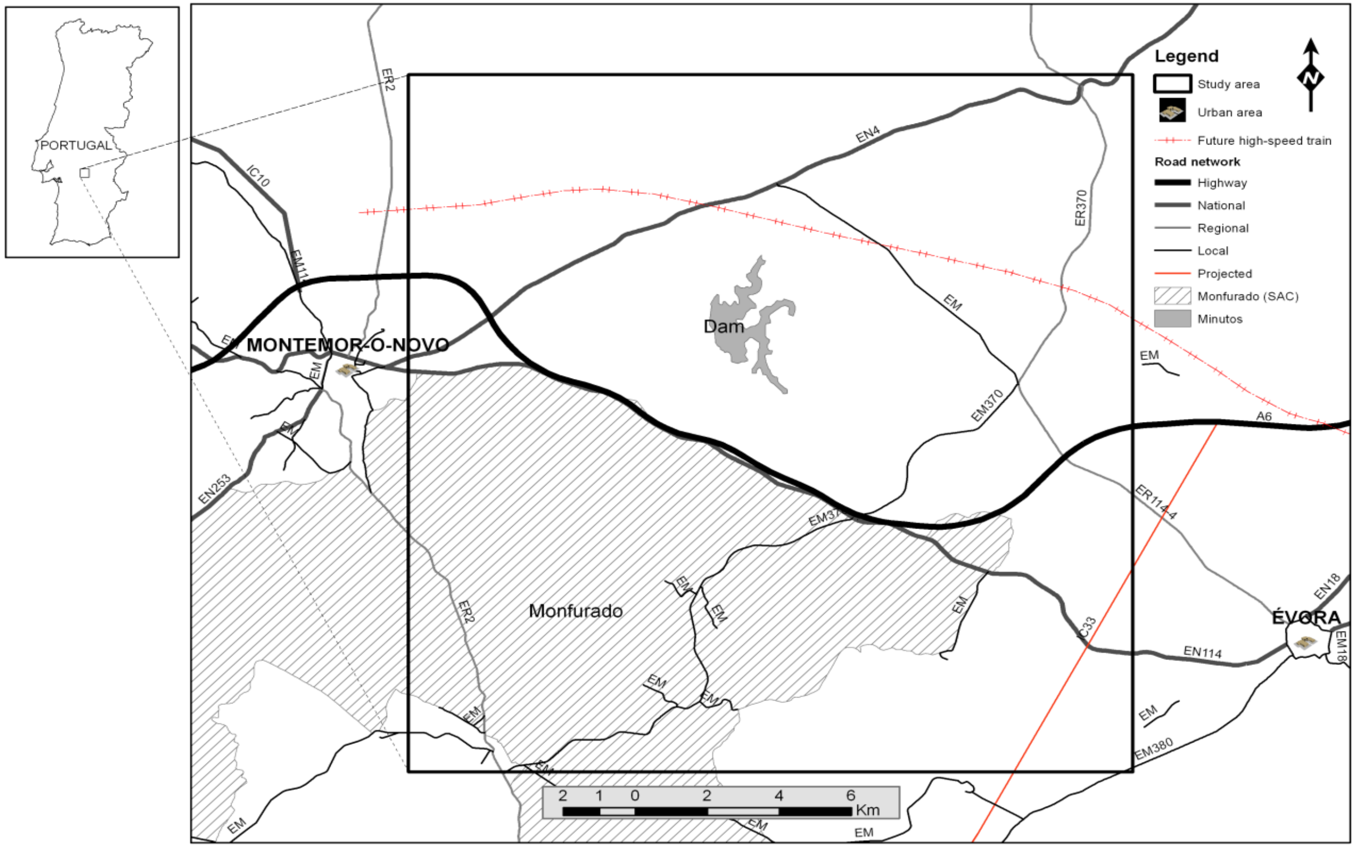

Figure 4-1. Study area with almost 42.500ha spitted by the network of roads and future railway trans

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).

4.3.3 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 4-2).

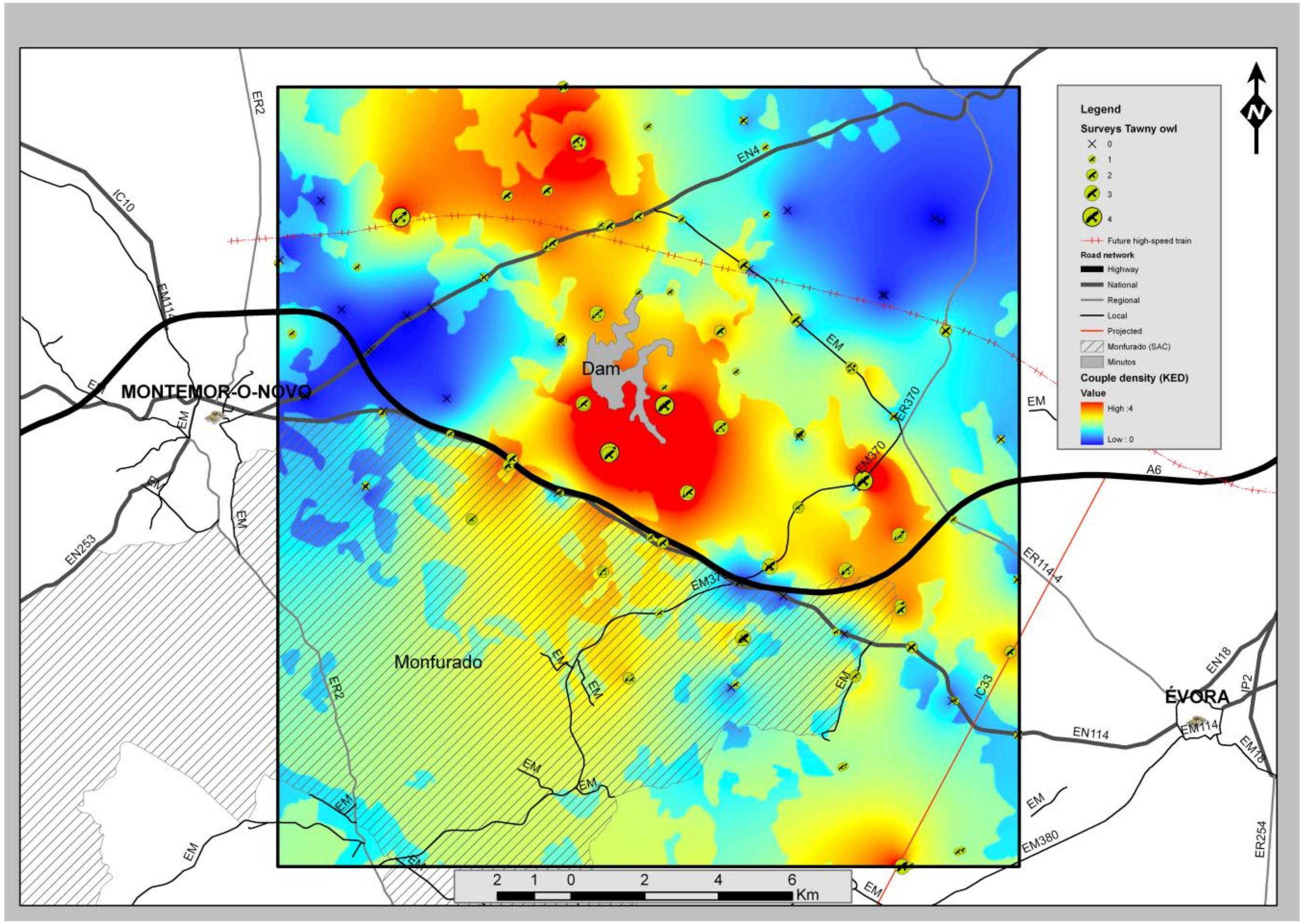

Figure 4-2. The 66 sampling survey sites of Tawny owl and the generated kriging with external drifts density surface. There is a central core of high density; the pattern is oriented in a NW-SE direction.

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 4-3). 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).

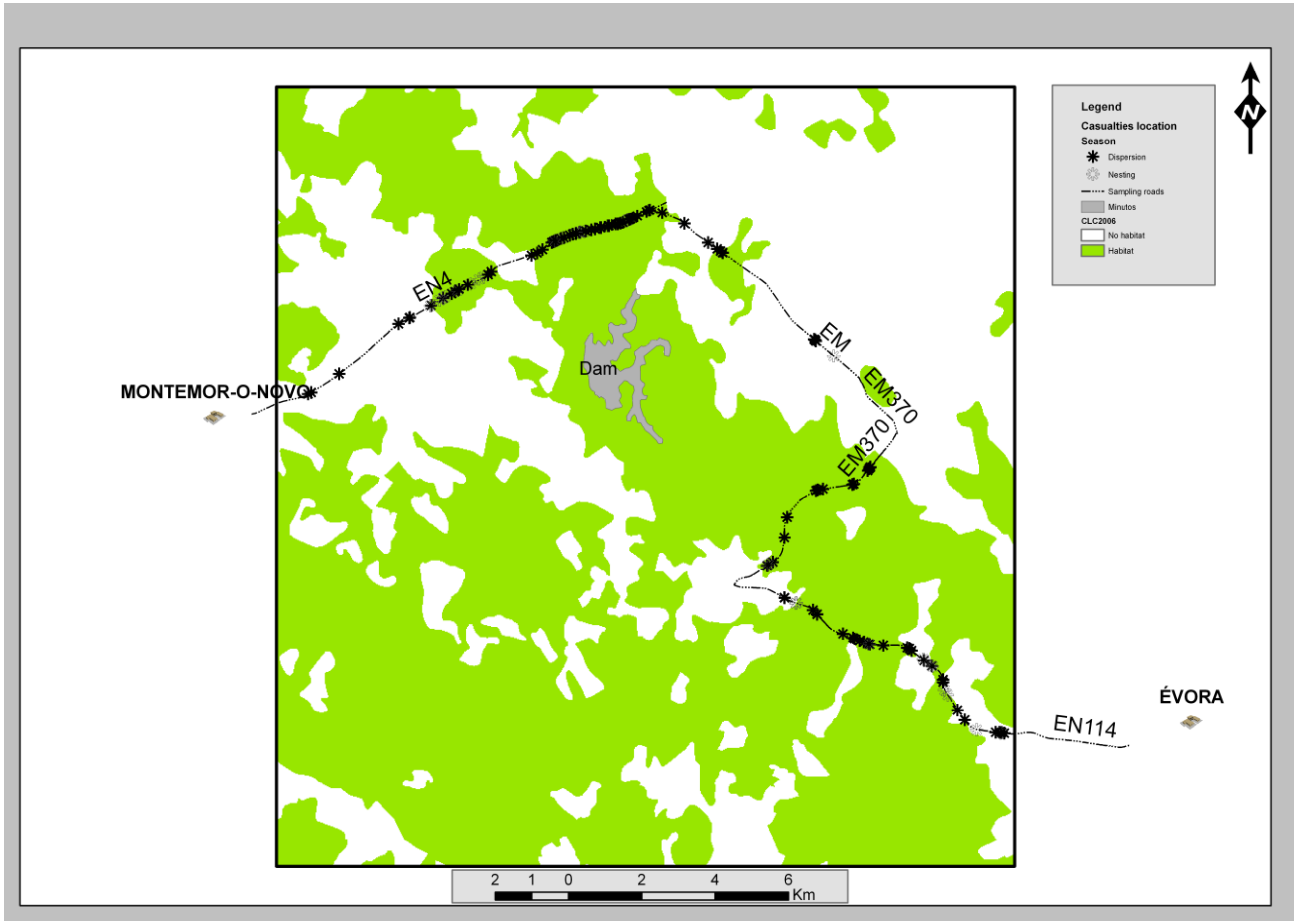

Figure 4-3. The 135 casualties' locations of Tawny owl, in the national road EN04 and EM370. The pattern reveals a close relation with the population density surface and by road split (barrier) areas of habitat shape.

4.4 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 point's surveys of our study provide reference units (position), and were used to interpolate species density and define patterns of casualty hotspots.

4.4.1 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.

4.4.2 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).

4.5 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 4-4); and, (b) a generalized linear model (GLM) to predict the probability and the number of casualties in each hexagon unit (McCullagh & Nelder, 1989).

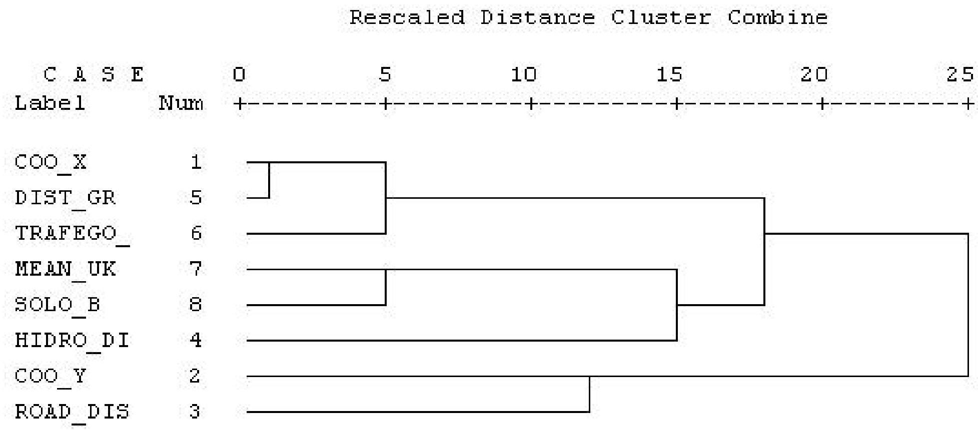

Figure 4-4. Dendrogram from the hierarchical cluster analysis, the land use (7) and density (8) are the most homogeneity environmental predictors

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 4-1). 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.

Table 4-1. 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

4.6 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 4-2).

Considering all point casualties (Figure 4-3) 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 4-5). The results of SaTScan highlight a significant number of mortality hotspots. Considering both seasons in 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 4-6). 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 4-7).

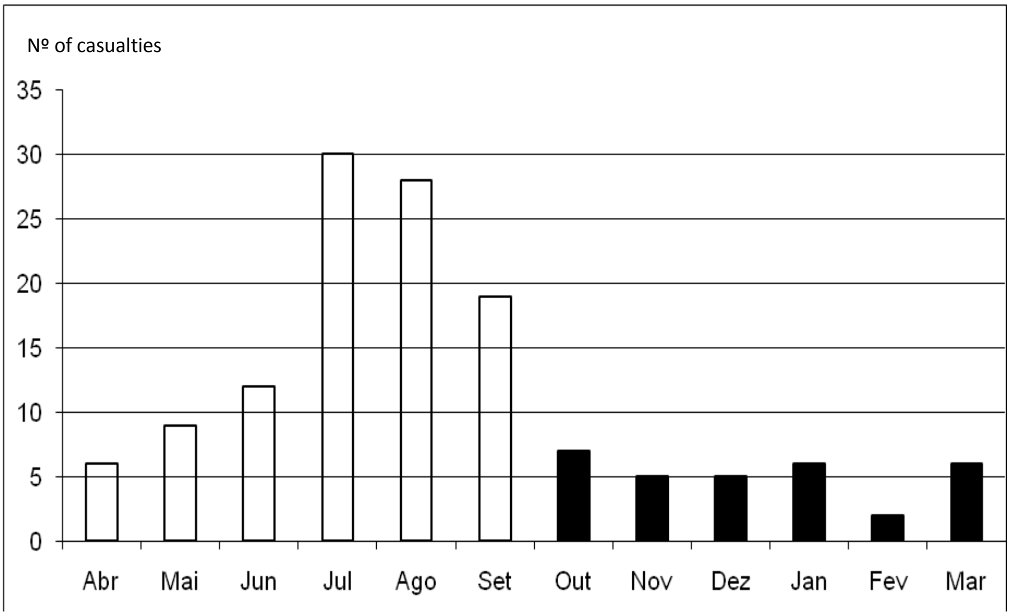

Figure 4-5. Seasonal dynamics of Tawny owl casualties' count in the survey time, line bars represent the migration and solid bars the nested season.

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 4-8). According to the model, we could identify 8 presently critical areas, and three future new areas of high impact (Figure 4-9). 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.

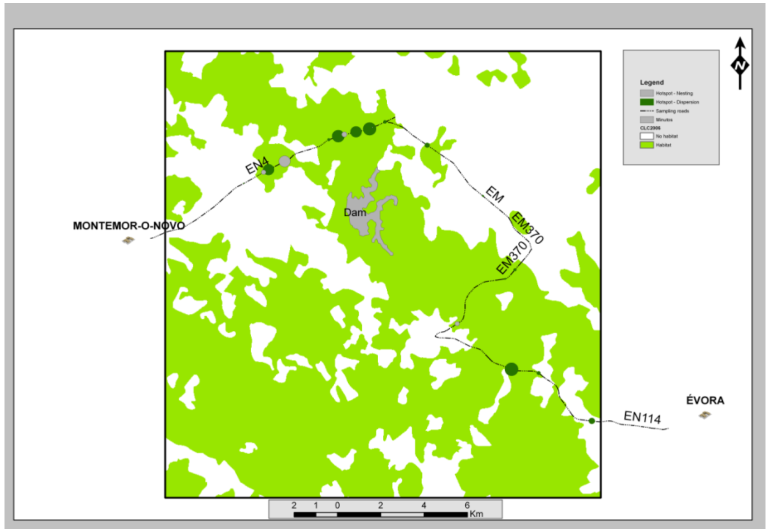

Figure 4-6. Mortality hotspots are tendency located on contiguity habitat patch.

Figure 4-7. 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.

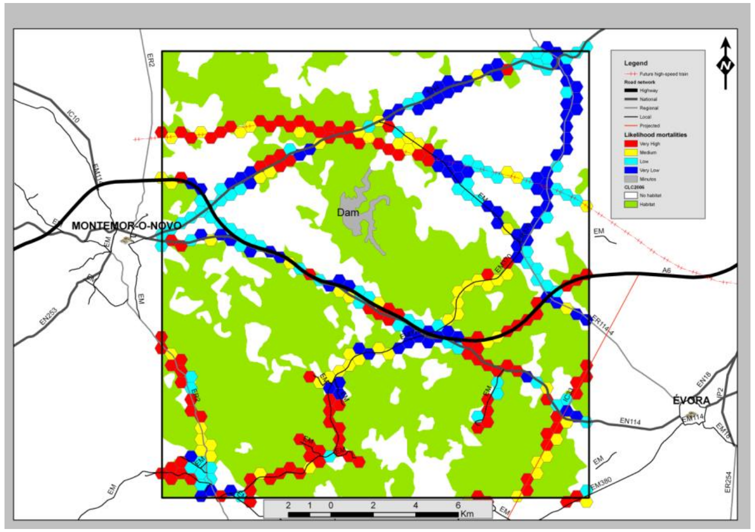

Figure 4-8. The generated spatial model of likelihood mortalities occurrences shows problematic areas of the impact of the existing and future infrastructures.

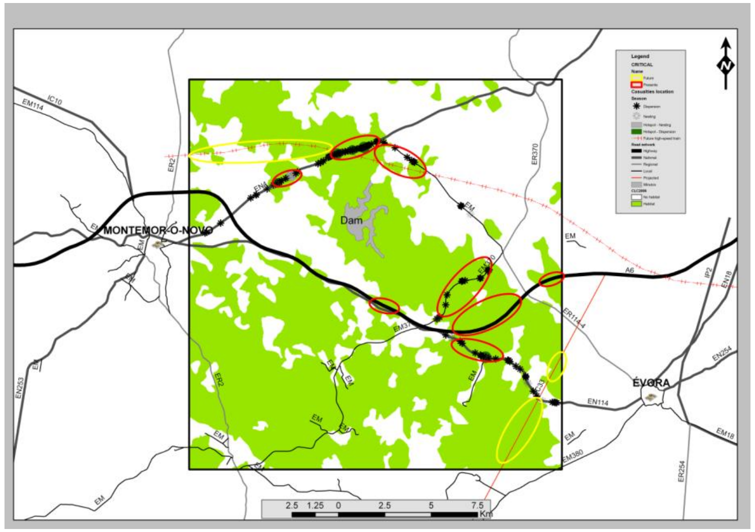

Figure 4-9. The present and the near future critical areas of infrastructures impact.

4.7 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 can 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.

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.

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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5 CONNECTIONS IN SCARCE HABITAT

"*It is more exciting and rewarding to work for connectivity than against fragmentation*"
P. Beier (2007)

Abstract

Connectivity is currently a central issue in landscape management and planning for the conservation of wildlife species occupying scarce habitat patches. In recent years, this issue has increasingly been addressed using methodologies based on spatial network analysis. Here, we propose a hybrid approach based on network analysis tools and empirical habitat suitability models to integrate connectivity on decision-making. The study is focused on a pond system used by the European pond turtle, *Emys orbicularis*, in a coastal area in southwestern Iberia. The main objective of the study was to illustrate how the output of graph models may be useful to guide habitat management and planning. We assessed ponds according to three complementary structural and functional properties derived from a graph model: (1) pond importance as measured by the sensitivity of the overall connectivity to each pond loss, (2) pond coreness, used to identify the most cohesive pond subsystems and (3) pond betweeness, which measure the importance of ponds as stepping stones. The graph model took into account a resistance-to-movement surface, the maximum traveled distance and a habitat suitability model based on field sampling. Pond importance and coreness were shown to be positively related to occupancy, especially by turtle's youngest age classes, suggesting an important contribution of connectivity attributes for turtle populations. We discuss the ways these pond connectivity-related attributes may be helpful to assist and optimize management efforts for the conservation of the European pond turtle in the study area.

Keywords: Connectivity; *Emys orbicularis*; Fragmentation; Graph analysis; Pond network

5.1 Introduction

The increasing fragmentation of habitat is a major consequence of human actions in the landscape. An important result of habitat fragmentation is the loss of connectivity between habitat patches used by species. According to Taylor et al., (1993) landscape connectivity "is the degree to which the landscape facilitates or impedes movement of organisms among resource patches". Species need connectivity to obtain the basic resources to ensure survival and the diffusion of genes flow (Pardini et al., 2005). Fragmentation acts directly or indirectly on home range sizes, breeding success, productivity areas and mobility of species (Malanson, 2002; Nikolakki, 2004). Habitat fragmentation may reduce a species' geographical distribution and limit the viability of local populations (Chetkiewicz et al., 2006).

Conservation planning and landscape defragmentation are important instruments in policy and practice to promote connectivity (van Bohemen, 1998). In fact, in the context of conservation research, a major concern has been on habitat connectivity, especially the design of ecological habitat corridors (Beier et al., 2008; Chetkiewicz et al., 2006). In order to identify the relevant habitat attributes (e.g. size, connectivity, ecological function) to be accounted for in conservation actions at the landscape level, information about specific ecological processes of target species is needed (Bowne et al., 2006). The identification of habitat attributes provides important guidelines for developing connectivity models. A simple approach is through the use of habitat models describing relationships between spatial patterns of a given species' attribute (e.g. distribution of individuals) and a set of habitat or landscape attributes (Guisan & Zimmermann, 2000).

One way of assessing the structure and the behavior of a spatial complex system is to identify its properties on a graph model (Green et al., 2007). This approach is especially useful to address questions related to network structure, objects centrality, their interactions and flow efficiency (Green et al., 2007). A graph provides a simple method of representing habitat patches within a landscape matrix. Habitat patches are defined by a set of nodes connected by links, each with its own attribute value (Urban &

Keitt, 2001). A network may contain several subnets or components (Green et al., 2007), defined as a set of linked nodes for a given threshold distance (Saura & Pascual-Hortal, 2007). An important feature of networks is the existence of cut-nodes, which are those nodes whose removal would disconnect one group (component) into two or more subcomponents. Another important feature is the existence of a maximal complete subgraph (clique), which is defined by the node subset such that every two nodes are connected by a link. These and many other relevant network properties can be computed using graph models, which makes them potentially useful tools in conservation planning (Andersson & Bodin, 2009; Bodin & Norberg, 2007).

Although it has often been claimed that graph models provide valid and useful tools for land management and conservation planning (e.g. Ferrari et al., 2007; Minor & Urban, 2008; Urban & Keitt, 2001), very few studies have demonstrated the effectiveness of such approaches on concrete conservation issues (but see e.g. Andersson & Bodin, 2009; Fortuna et al., 2006; Pascual-Hortal & Saura, 2008). In the present paper we provide an example of application to a concrete land management problem: the conservation planning of an endangered species (European pond turtle) inhabiting temporary pond systems at a region under strong agriculture intensification.

5.2 Case study

The European pond turtle, *Emys orbicularis*, is one of the two native freshwater turtles that live in the Iberian Peninsula. Portuguese populations represent the western limit of its western Palearctic distribution. In many European countries, including Portugal the species is considered “endangered” according to the criteria of the International Union for Conservation of Nature (Cabral et al., 2005). In Portugal, temporary pond systems are among the most important habitats for this species (Segurado & Figueiredo, 2007; Segurado & Araújo, 2008).

Turtle movements among ponds have been widely reported and recognized as crucial for populations' persistence (Bowne et al., 2006). While adult turtles often perform intra-annual movements between ponds throughout the annual hydrological cycle, hatchlings and juveniles tend to remain in the same pond throughout their activity period and are more demanding in terms of habitat requirements (Cadi et al., 2004). However, little is known about the true importance of pond connectivity for turtles' conservation. Furthermore, to our knowledge, quantitative approaches to connectivity of spatial network have never been considered in conservation planning and landscape management aiming at the conservation of this species.

The main objective of this work is to illustrate how connectivity-related pond attributes may guide landscape management decisions for the conservation of a European turtle population occupying a pond network system in southwestern Portugal. These pond systems had suffered from a recent rapid agricultural intensification, with many ponds being drained or turned into permanent reservoirs. As solid data on turtle's population dynamics within this pond network is generally lacking, the use of indirect information such as habitat modeling and network analysis may provide useful guidelines for conservation planning. We first assessed the structure of the spatial network connectivity of turtles' pond habitat patches, taking into consideration the species' behavioral and ecological information: 1) a distance threshold based on the maximum terrestrial traveled distances found in this species; and 2) an empirical habitat model. Then we estimated several connectivity-related parameters which helped to prioritize conservation efforts, namely by ranking ponds according to their relevance for maintaining the overall connectivity of the pond system. Data on age structure are available for a set of ponds, which we used here to evaluate and compare the several connectivity attributes as adequately representing pond importance in terms of populations' status. In fact, age structure is one of the most important indicators for turtle conservation (Gibs & Amato, 2000) as a consequence of life history traits such as their high longevity, delayed sexual maturity and great change of survival rates from hatchling to the adult stages.

5.3 Methods

The management of spatial data (ortophoto-maps interpretation, queries, vector to raster conversions and development of the resistance surface) was performed using ArcView 3.3 GIS software (ESRI 2002). Least-path distance calculation was performed using Pathmatrix extension for ArcView 3.x (Ray, 2005). All statistical analyses were performed using functions and routines implemented in R software version 2.7.1 (R Development Core Team 2008). Graph analysis and the computation of connectivity indices were conducted with the complementary applications, Pajek 1.23 (Batagelj & Mrvar, 2008), NetDraw 2.083 (Borgatti, 2002), Conefor Sensinode 2.2 (Saura & Pascual-Hortal, 2007) and LaNet-vi (Beiró et al., 2008).

5.3.1 Study area

The study was carried out on the coastal plain of southwest Portugal (37º30'N, 8º57W), in the Southwest Alentejo and Vicentine Coast Natural Park (Figure 1). The terrain geomorphology consists of a quaternary platform marked by a flat plain with slopes less than 1º, which is abruptly interrupted in the west by the coastal cliffs of the Atlantic Ocean. The area is bordered in the east by a chain of small mountains, *Serra do Cercal* and *Carregoussal-S.Teotónio*, with tectonic origin (Pereira 1995). The landscape is bisected by the Mira River, running in a predominantly south-north direction, which has its origin in the *Caldeirão* Mountains of the Algarve region. The area has low human density (≈50hab/km^2), but with focal urban spread and crossed by a network of local and a national roads. Tourism is increasing in popularity in the region, mainly on the coastal beaches. There is a substantial human presence and all kinds of vehicle traffic during spring and summer.

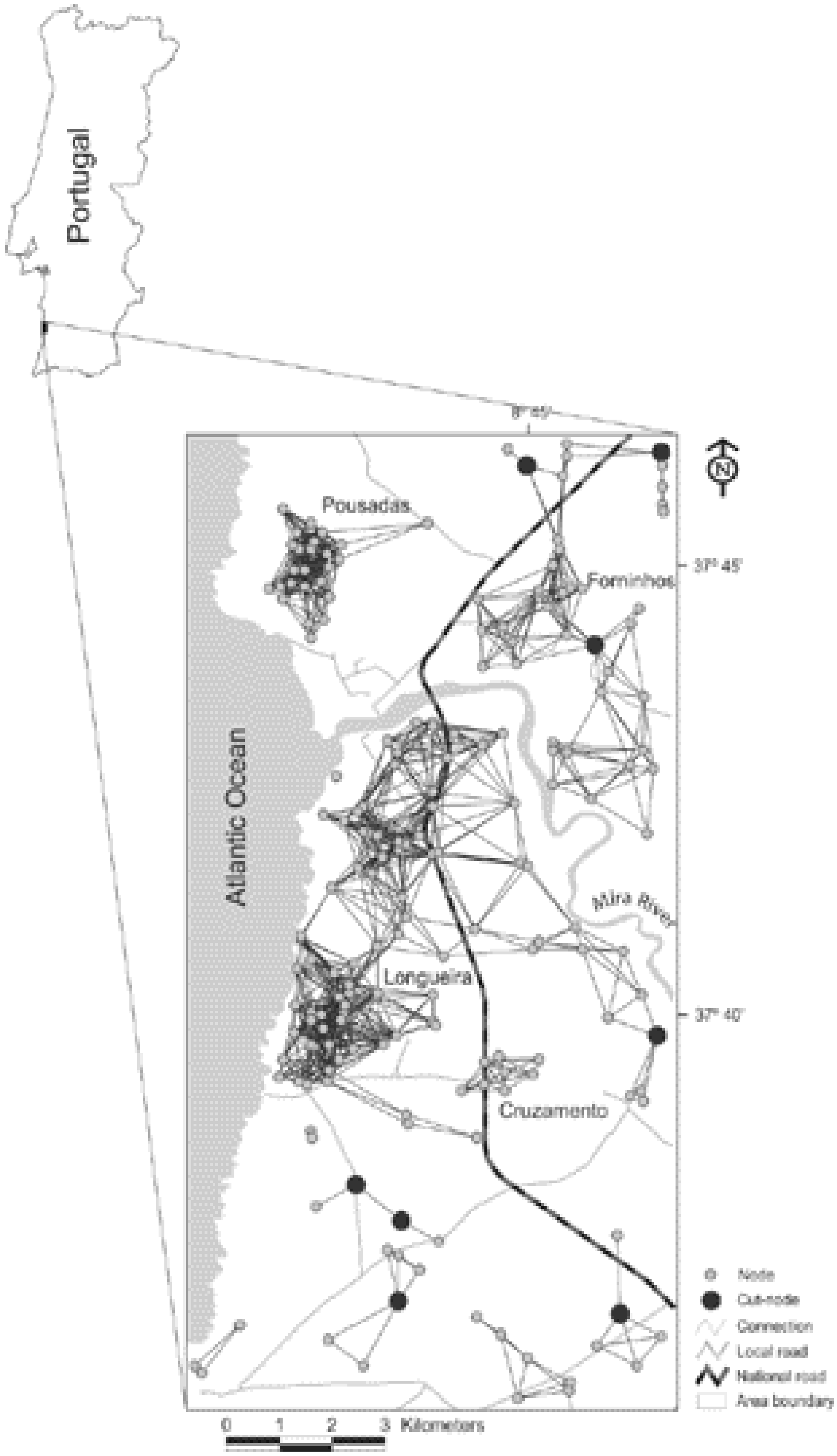

Figure 5-1. Study area with the main natural barriers (Atlantic ocean, salt river and asphalt road network) online at: http://maps.google.pt/maps/ms?hl=pt-PT&client=firefox-a&ie=UTF8&msa=0&msid=104904933274161512233.00046a7c80f1be8ac7373&t=h&z=11. The pond network (with 11 components) and respective graph connections for a threshold distance of 2 000m. Larger black dots represent cut-nodes, which suggest a greater risk of connectivity disruption in Forninhos and in the scattered components of the southern region of the study area.

The soils of the study area are very suitable for agriculture. The landscape matrix is dominated by agricultural lands and natural or cultivated pastures. Since 1990, the less intensive farming system based on cereal-fallow rotation has been replaced by irrigated crops, mainly corn and greenhouse plantations (Beja & Alcazar, 2003). Water for irrigation is transported through a system of canals and stored in small reservoirs. Tree cover is restricted to a few small woods and windbreaks and is dominated by *Pinus pinaster* and *Eucalyptus globules*.

Shallow temporary ponds of varying size are scattered throughout the area. Their hydro period follows the fluctuations of the water table, filling in winter and drying out sequentially, according to their size and depth, during the summer months. The water drainage through the irrigation canals is also an important source of water in field depressions, especially in summer. In recent years many of these ponds have been either drained or deepened by farmers and used as permanent reservoirs (Beja & Alcazar, 2003). Despite the increasing agricultural pressure, many ponds are still occupied by vascular plants, branchiopod crustaceans, aquatic insects and amphibians with substantial conservation value. Exotic predators such as the American crayfish, *Procambarus clarkia*, have invaded many of these ponds. Nevertheless, these temporary pond systems have seldom been the focus of biological field surveys and there is a dearth of ecological information about them (Beja & Alcazar, 2003).

5.3.2 Data collection

We sampled a total of forty-three ponds in the study area during spring and summer months, from 2003 to 2006, in order to find freshwater turtles. We carried out a minimum three-day trapping session for each site using small baited hoop nets (30 x 60 cm). The number of traps used at each site was proportional to the surface area of the pond. We permanently marked turtles by notching the marginal scutes, according to a coding system. Turtles were assumed to be absent from a pond if none were caught within the three-day trapping session.

We used a catalogue of ortophoto-maps from the summer of 2005 to identify and collect environmental descriptors of ponds in order to assess their spatial structure. The identification of ponds was based on the cover contrast. The use of summer images allowed the identification of most ponds, since the contrast between the pond vegetation and the matrix is highest during this season. Usually, the matrix is very dry and the pond depression keeps water and has green vegetation. We compiled environmental variables for a total of 191 ponds using the ortophoto-maps at fixed scale of 1:3.000. The average pond area is relatively small (0.35ha); the largest pond has an area of 7.10ha.

5.3.3 Habitat suitability models

We used a generalized linear model (GLM; McCullagh & Nelder, 1989) assuming a binomial distribution of errors and a logit link function (logistic regression) to determine the relationship between the presence and absence of *Emis orbicularis* at the sampled ponds and several explanatory variables derived from aerial ortophoto-maps and GIS features. We considered the following explanatory variables: pond area, presence of aquatic vegetation, landscape matrix, distance to roads and distance to the hydrographic network. The resulting predictive model allowed the probability of occurrence to be computed for each sampled and non-sampled pond. The probability of occurrence was assumed to be a measure of habitat suitability.

In order to obtain the most parsimonious model, we used an information-theoretical approach (Burnham & Anderson, 2002) for model selection. In a first step, we pre-selected thirteen candidate models based on the criteria of: (i) biological significance;

(ii) significant or near significant contribution of variables to model improvement (ANOVA, $p<0.1$); and (iii) Pearson correlation among variables lower than 0.7. In a second step, we compared the pre-selected candidate models using Akaike Information Criterion (AIC) weights (Burnham & Anderson, 2002) and selected the final model. The AIC weights sum to 1 for all candidate models and can be defined as the probability that model *i* would be selected as the best fitting model if the data were collected again under identical circumstances (Burnham & Anderson, 2002). We used a jacknife procedure to validate the final model. The assessment of the model's accuracy was based on the area under the Receiver Operational Curve (ROC), the AUC Index (Fielding & Bell, 1997). This measure assesses how far from chance the model predicts occurrence, varying from 0.5 (random classification) to 1 (perfect classification). The main advantage of using this measure is that it does not require the selection of a probability threshold value. We then computed the probability of occurrence for the remaining unsurveyed ponds.

5.3.4 Effective distance computation

We used land cover map of year 1990 updated from ortophoto-maps of 2005, to develop the resistance surface to turtle movements. Resistance maps are usually in the form of grid cell layers with pixel values representing the permeability of travel through each cell (Ray et al., 2002). Lowest resistance values were assigned to habitat patches (ponds and rivers), which may function either as habitat or stepping-stones. The highest values were assigned to spatial barriers that hinder turtle's movements (e.g. roads). Deflected-movement features (e.g. bodies of salt water) were defined as void class ("no data"). Resistance in the matrix (e.g. pastures and crop fields) was considered higher than in habitat patches but lower than in hindering barriers (Table 5-1).

We selected a set of equidistant resistance values scaled from 1 to 100 (*equidistant* scenario), based on the literature (Bowne et al., 2006), expert judgment and the specificities of the study area. We then used the resulting resistance surface to infer least-cost paths among ponds (Tomlin, 1990), which allowed effective distances to be computed (Moilanen & Hanski, 2001; Ray, 2005). In order to assess whether very contrasting selection of values, although maintaining the same rank order, would change significantly the connectivity indices, we performed an uncertainty analysis using a worst-case scenario approach (Beier et al., 2009; Burgman et al., 2005). We considered two contrasting set of values: a set of values that were compressed around the medium value of 50 (*compressed* scenario) and a set of values that were closer to either the minimum (0) or the maximum (100) values (*contrasting* scenario).

Table 5-1. Conversion values of resistance surface of modeling scenarios.

Type	**Associated movement**	**Equidistant**	**Compressed**	**Contrasting**
Rivers; Ponds	Highest survival movements and reproductive success	1	30	1
Natural pastures	Successful movements	25	40	5
Shrubs; Cork; Uncover areas;	Consistent movements	50	50	50
Orchards; Permanent crops; Eucalyptus and Pinus plantations; Tall shrubs	Occasional movements	75	60	95
Salt marsh; Roads	Restricted movements	100	70	100
Urban areas; Beach; Salty water	Deflected movement	void	void	void

The network of ponds is considered connected when the effective distance among ponds is equal to or less than the value of the threshold distance established to the model species (Bunn et al., 2000; Ferrari et al., 2007; Keitt et al., 1997; Urban & Keitt, 2001). The critical distance effects are noted when individuals cannot reach the threshold; this may result in local extinctions or fragmentation (Keitt et al., 1997). We assumed a symmetrical dispersal, i.e., the distance from pond *a* to *b* is the same than from *b* to *a* (Saura & Pascual-Hortal, 2007), since the terrain of the study area is relatively flat.

We used a distance of 2 000 m as the threshold distance. This distance is assumed to represent the maximum distance travelled by a turtle across land at least once during lifetime. In fact, this value is an educated guess, since long term data on turtles' movements are scarce. However, there are a few studies based on capture-recapture programs or telemetry data that report movements from a few meters to more than 1 km to nesting sites undertaken by female European pond turtles (Rovero & Chelazzi, 1996; Jablonski & Jablonska, 1998; Mitrus and Zemanek, 1998; Paul & Andreas, 1998; Schneeweiss & Steinhauer, 1998; Schneeweiss et al., 1998; Novotny et al., 2004), although it is not always clear whether these movements are exclusively undertaken across land (Mitrus, 2010). Nevertheless, it is assumed that movements up to 1 500-2 000 m across land are commonly found for this species (Ficetola et al., 2004). Furthermore, it is possible that land movements are more important for populations that live in wetlands suffering seasonal draughts (Ficetola & Bernardi, 2006), which is the case of the studied populations.

5.3.5 Structural and functional properties

We measured structural and functional properties of ponds within networks using several indices based on graph analysis. A graph network is represented by $G = (N,L)$, where *N* is a set of *n* nodes connected by *l* links (*L*). In this case study, the nodes represent discrete habitat patches (ponds) surrounded by inhospitable habitat (non-habitat). The links represent the relationships between the linked nodes, identified by the least-cost paths between the ponds (in most cases the water lines). Ponds' network properties of sensitivity, coreness and betweenness were computed and compared to the presence-absence of turtles in ponds, separately for adults and hatchling/juveniles. Younger age classes were assumed to be more selective regarding pond attributes as they tend to be more sedentary (Cadi et al., 2004).

5.3.5.1 Node Importance

Node importance expresses the importance of each node for the overall connectivity of a network. We estimated this property for each pond using the variation of the Probability of Connectivity (*PC*) index of the network after their removal. *PC* is a measure of the overall connectivity of a network that takes into account the habitat availability (e.g. patch area), or other relevant patch attribute (habitat suitability in this study), the dispersal probability, as measured by the effective distances among patches, and the number of links per patch (e.g. see Saura & Pascual-Hortal, 2007). *PC* is expressed by:

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j p_{ij}^*}{A_L^2} \qquad [1],$$

where ai and aj are the attributes (habitat suitability) of ponds *i* and *j*, respectively and *AL* is the total landscape area (area of the study region, comprising both habitat and non-habitat patches).

Node importance is then expressed by the *delta-PC*, which is given by the expression:

$$dPC(\%) = \frac{PC - PC'}{PC} \times 100 \qquad [2],$$

where *PC* is the probability of connectivity when the pond is present in the landscape and *PC′* is the probability of connectivity after the removal of that pond (Keitt et al., 1997; Pascual-Hortal & Saura, 2006; Rae et al., 2007; Urban & Keitt, 2001).

5.3.5.2 Coreness

The notion of coreness was original introduced by Seidman in 1983**.** The *k-core* or a core of order k is a decomposition index that is usefully to identify the network fingerprinting by simplifying the graph topology in a destructively way (Alvarez-Hamelin et al., 2005; Batagelj & Zaversnik, 2002). In a graph G = (*N*,*L*) of |*N*| = n nodes and |*L*| = *l* links; a *k-core* of *G* is computed by removing recursively the nodes (and the respective links) with number of connections (degrees) lower than *k*, until all nodes in the remaining graph have at least degree *k*. For example, a *2-core* of a graph is the resulting sub-graph after cutting all the nodes with only one connection, and so on until a graph with only the most connected nodes is obtained (i.e. with maximum coreness).

Here, we used *k-core* to help visualizing and highlighting the hierarchical and structural organization of the pond network. We performed the computation using a general visualization algorithm of *k-core* decomposition, by progressively selecting and filter sub-groups (shells) of higher *k* and central cores of nodes (Alvarez-Hamelin et al., 2005). The position for each node in the plot depends both on the position of his component and his own relative position inside. Moreover, components are deployed in circular sectors according to their size, and relative nodes position depends on the k-core decomposition from his component. Central nodes of each component are deployed in circular sectors, where each of them is a clique.

5.3.5.3 Betweenness

The betweenness index is a measure that identifies nodes (ponds) with stepping-stone functions (Minor & Urban, 2007). It is computed by identifying the shortest paths linking pairs of nodes, and then counting the number of times those paths cross each nodes. Nodes have higher betweenness if they occur at many shortest paths. For a graph *G*, the betweenness *CB(n)* for node *n* is given by:

$$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}} \qquad [3],$$

where σst is the number of shortest paths from s to t, and $\sigma st(n)$ is the number of shortest paths from s to t that pass through a node *n*. Nodes with highest betweenness index are most often cut-nodes and are considered to have the same ecological relevance (Minor & Urban, 2007).

5.4 Results

The resulting pond network structure, based on the 2 000 m threshold distance, is composed of 11 components, although only three showing significant dimensions (Figure 1). The main components include: (i) a group of eighty seven ponds in the

Longueira area (45% of the existing ponds), (ii) a group of forty-three ponds in the *Forninhos* area (22% of the existing ponds), and (iii) a smaller group of twenty-six ponds in the *Pousadas* area (14% of the existing ponds) and (iv) eigth scattered components representing thirty-five ponds (18% of the existing ponds); among these, the main component is located in the *Cruzamento* area. The *Forninhos* component contains three ponds that may act as cut-nodes, i.e., with three possibilities of component fragmentation, the *Longueira* component contains only one cut-node and the scattered components show four possibilities of fragmentation into new components (Figure 1). The component with a larger clique subset is *Longueira* with 22 ponds, followed by *Pousadas* (21), *Forninhos* (17), and *Cruzamento* (7).

No significant differences (Pearson product-moment correlation, $P < 0,001$) were found between the selected *equidistant* scenario and the two worst case scenarios of resistance surface for dPC (Pearson $r = 0.98$ for the *contrasting* scenario and Pearson $r = 0.99$ for the *compressed* scenario) and coreness (Pearson $r = 0.96$ for the *contrasting* scenario and Pearson $r = 0.94$ for the *compressed* scenario). Weaker correlations among scenarios were however found for the betweeness values, especially for the *compressed* scenario (Pearson $r = 0.81$ for the *contrasting* scenario and Pearson $r = 0.15$ for the *compressed* scenario). For many ponds, especially in the Longueira and the Pousadas components, the betweeness values remained relatively unaltered. The most obvious changes occurred on the southern scattered components, where a general increase of betweeness was observed. The pond network structure also changed substantially among different scenarios of resistance surface (Figure 2). The main difference between the *equidistant* and *contrasting* scenarios is on the scattered components in the southernmost region of the study area: in the *contrasting* scenario these components form a single component. In the *compressed* scenario the network structure changes more markedly. The scattered and the *Cruzamento* components are now linked to the *Longueira* component. The number of components decreased from 11 in the *equidistant* scenario to six in the *contrasting* scenario and to three in the *compressed* scenario.

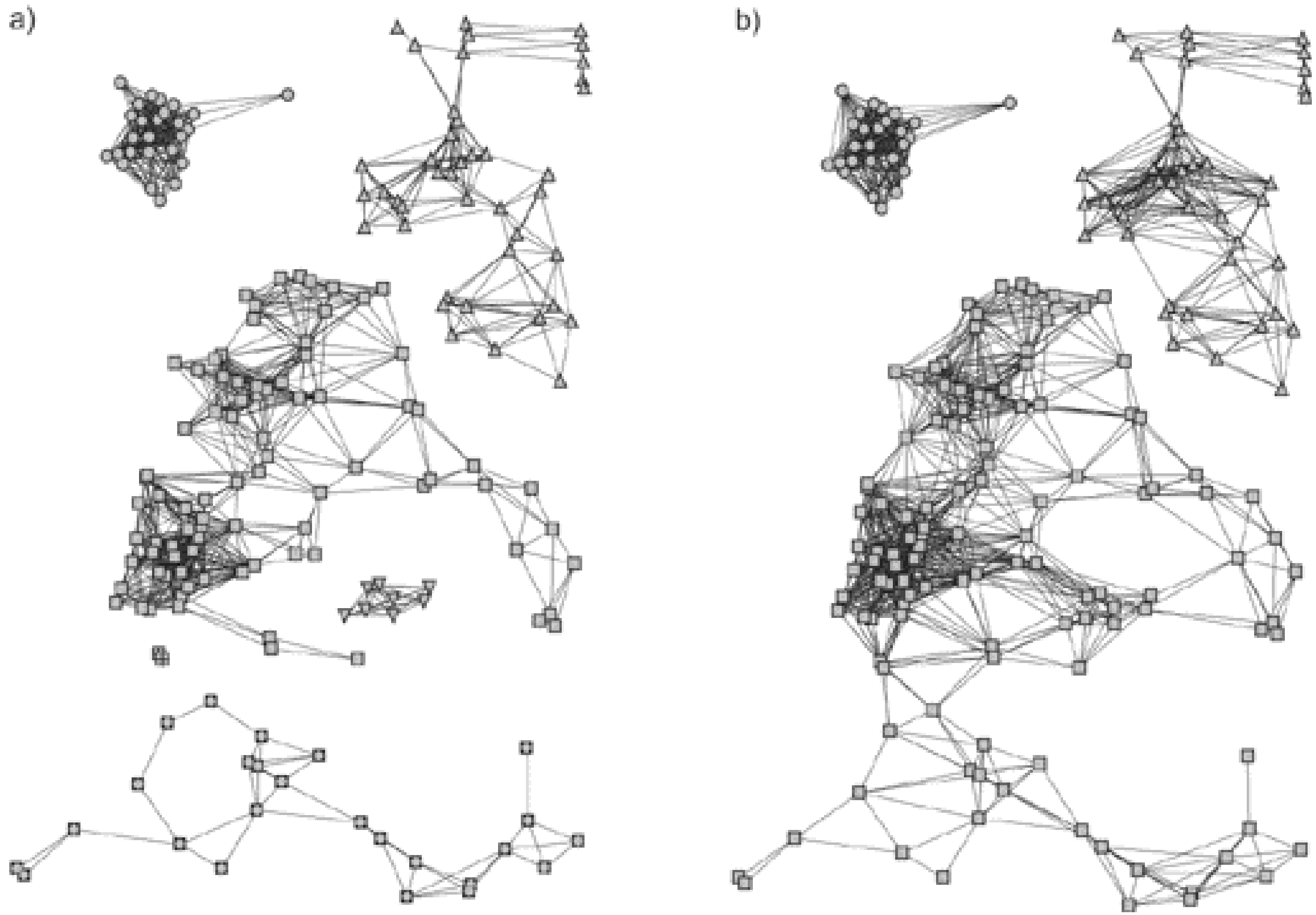

Figure 5-2. Network structure for the different surface resistance scenarios: a) Contrasting and b) Compressed. Dot shapes define the different components.

The selected habitat suitability model for European pond turtle in the study area had an Akaike Weight of 0.42 and included three variables: longitude (negative effect), presence of aquatic vegetation (positive effect) and pond surface area (positive effect), as expressed in Table 5-2. The jackknife AUC estimate for the model was 0.82, which is considered a good agreement according to Swets' (1988) rule.

Table 5-2. Summary of the final selected model of pond habitat suitability.

Variable	Coefficient	Std. Error	z value	Pr(>|z|)
(Intercept)	109.3047	52.3565	2.0877	0.0368
Longitude	-0.0008	0.0004	-2.1214	0.0339
Pond surface area	0.0002	0.0001	1.7176	0.0859
Presence of vegetation	2.4691	1.0577	2.3343	0.0196

The map of habitat suitability, as measured by the probability of species occurrence, shows a clear west-east gradient. The suitable habitats are mostly located along the flat areas near the coastline, mainly occupied by semi-natural pastures (Figure 3A). There are three main groups of ponds with high habitat suitability: (i) the *Longueira* group, (ii) the *Lagoa Tinta* sub-group which is connected to the former and (iii) the *Pousadas* group. The d*PC* index, which combines the topological position (average degree is 11.63 with a maximum value of 30) and habitat suitability of ponds, shows two main pond groups with high node importance values in *Longueira* and *Pousadas* (Figure 3B).

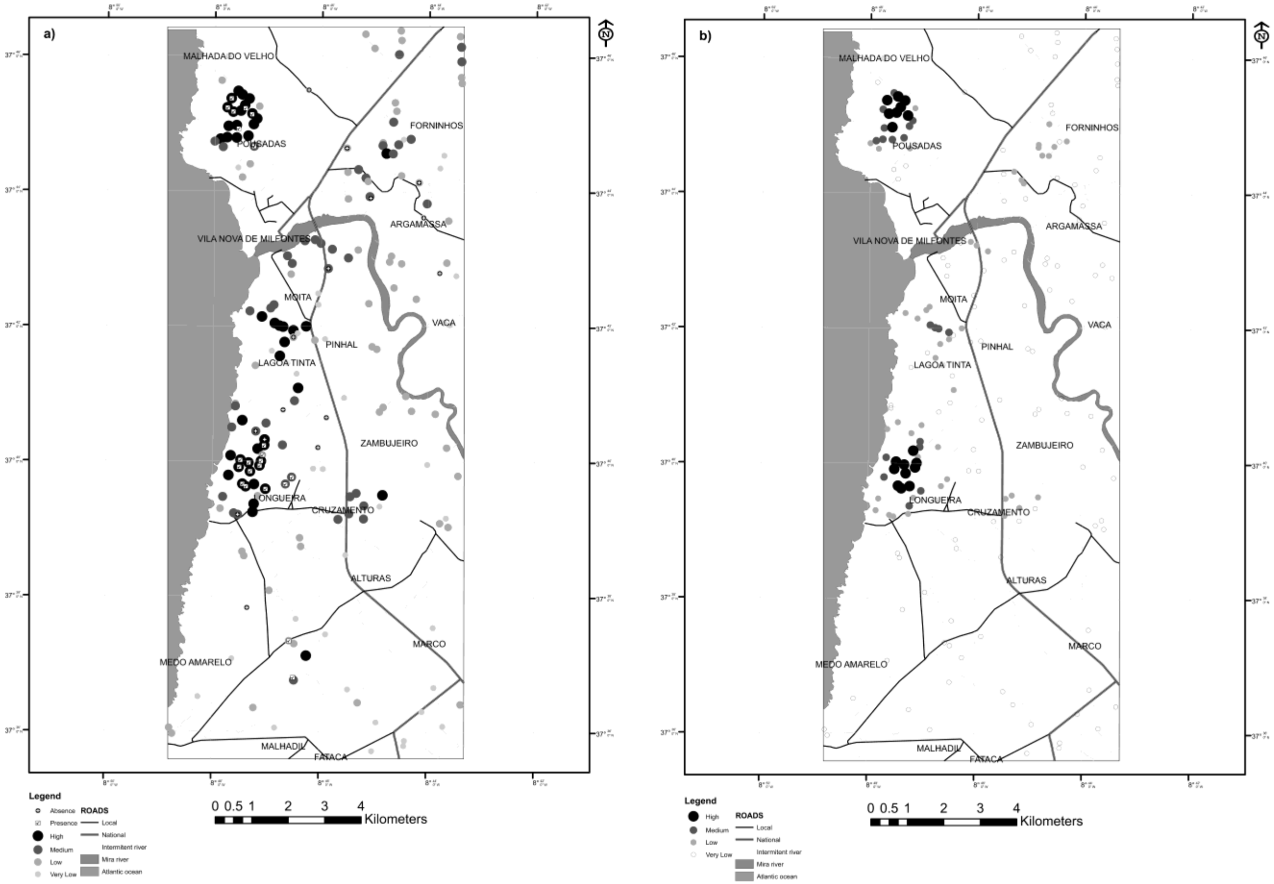

Figure 5-3. (a) Sampling sites, observed presence/absence and the predicted habitat suitability (as measured by probabilities of specie occurrence) for European pond turtle, according to the GLM model; (b) individual contribution of each pond importance to the overall connectivity, as measured dPC. The bins values are grouped by natural breaks of four high-low intervals.

According to the k-core decomposition index plot (Figure 4) the network contains two similar components, the *Longueira* and *Pousadas*, both showing high *k-core* values (16 and 14, respectively), with very well structured shells. The two components have very similar configurations, with a cohesive coreness of protected nodes, though the *Longueira* component shows a greater number of hierarchically linked nodes. A third component was identified in the *Forninhos* area with a k-core of 8, hence with a less cohesive structure compared to the other two components, but also showing a peripheral multi core configuration. The *Cruzamento* component, with a k-core value of 6, represents the lowest level of the hierarchical structure of components.

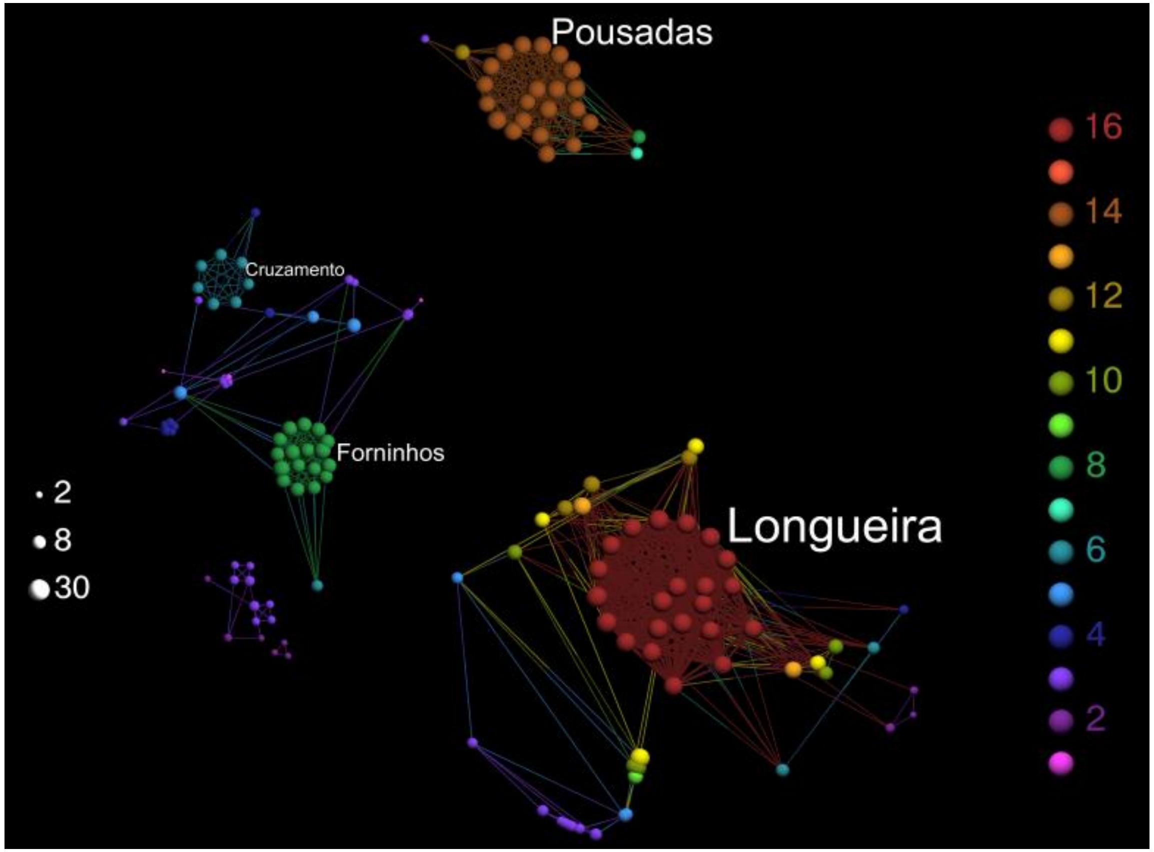

Figure 5-4. K-core decomposition shell index of the 191 ponds. The dots' positions are based on polar coordinates; dot colors between warm-cold express the coreness value (high-low, respectively), and size represents the number of links per patch (e.g., red nodes in Longueira are the central ones in this component): composed by a 16-clique and other smaller cliques. Peripherical nodes for each component are positioned close to their neighbors in higher cores.

According to the betweenness index, most ponds with a stepping stone function are included in the *Longueira* and the *Forninhos* components (Figure 5). There is a central pond in *Forminhos* that shows a high betweenness index, which is simultaneously a cut-node. *Longueira* is the more extensive component, with a *diameter* (longest shortest path) of 10. The average shortest path length of the whole network is 0.89.

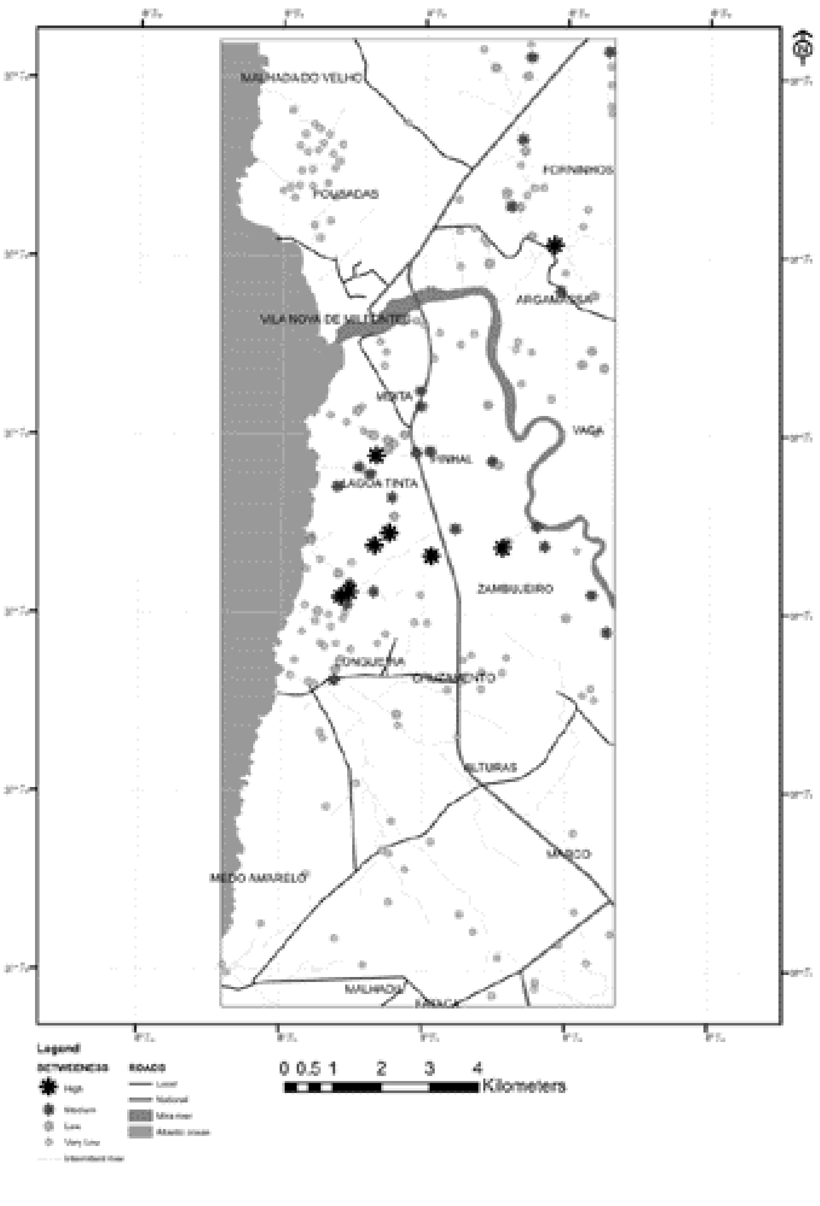

Figure 5-5. Betweenness index of ponds for European pond turtle according to 4 high-low rank. Most ponds with stepping-stone functions are located in the Longueira and Forninhos components, which are also the most extensive. The central node of Forninhos is simultaneously a cut-node.

The distribution of values of the several estimated pond attributes between occupied and unoccupied ponds shows that species presence is strongly influenced by the three connectivity attributes (Figure 6). This is especially the case for hatchling and juvenile individuals and for the k-core index. In fact, ponds occupied by hatchling or juvenile turtles are better distinguished from unoccupied ponds both according to habitat suitability and the two connectivity indexes (Figure 6).

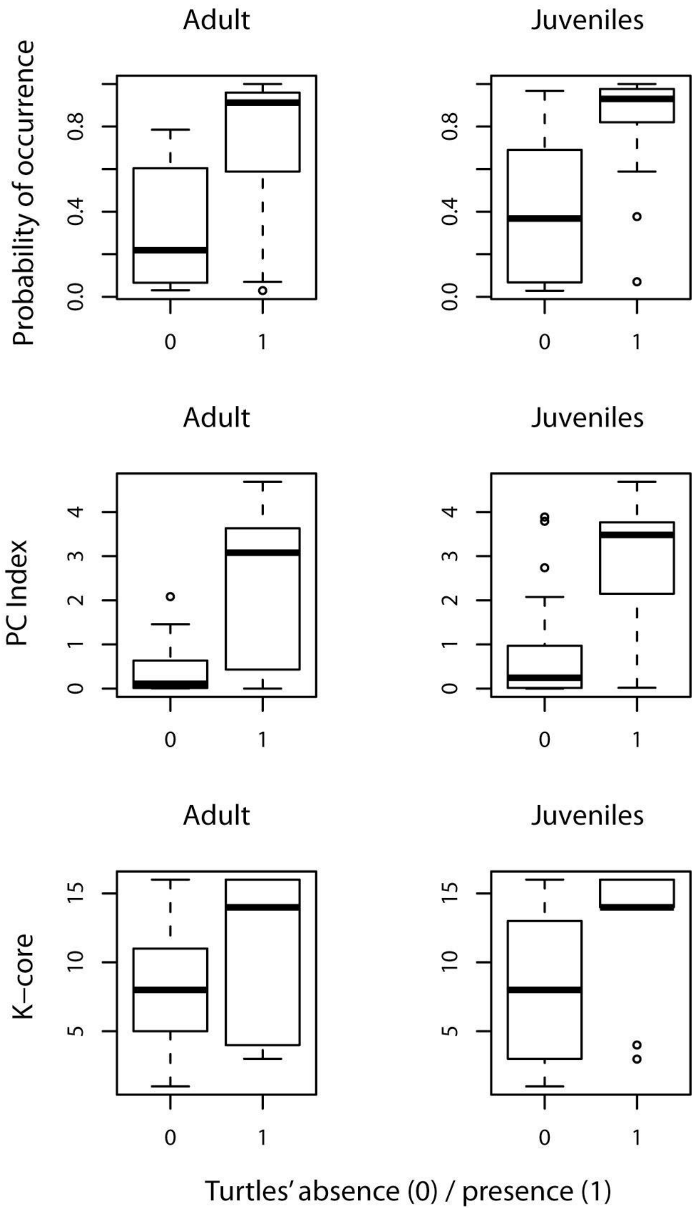

Figure 5-6. Boxplots showing differences between known unnocupied (0) and occupied (1) ponds (n=43) in habitat suitability (as measured by probabilities of occurrence), dPC and K-core values, separately for adult and juvenile turtles.

5.5 Discussion and conclusions

The results obtained in this study illustrates the potentialities of graph-based network analysis, at least as a first approach, to assist landscape management and conservation planning of populations occupying small scattered habitat patches within a non-habitat matrix. The connectivity-based attribute values successfully identified not only the two main pond systems occupied by the European pond turtle, but were also good indicators of those ponds showing good population status, according to age structure.

The alternative scenarios of surface resistance values affected considerably the network structure, especially when resistance values were compressed around a mean value (*compressed* scenario), which may represent a important limitation of the procedure. However, the dPC and coreness indices changed very little among scenarios. The betweeness values changed substantially between the *compressed* scenario and the other two. Yet, these changes were more marked on the ponds from less cohesive networks, especially on the scattered ponds in the southernmost region of the study area. We therefore strongly recommend that different alternative scenarios of resistance values should always be carefully checked. Especially for the identification of habitats with stepping stone function it is important to check the consistency of the resulting betweeness values under alternative scenarios. Nevertheless, the *compressed* scenario is possibly the less realistic situation. Indeed it is expectable that surface resistance values will be more dispersed between the two surface resistance extremes. The discussion that follows is based on the *equidistant* scenario since, as it represents the less extreme situation, is presumably closer to the reality.

Node importance values, as measured by *delta-PC*, allowed the identification of ponds whose destruction would have the strongest effect on the overall pond connectivity. Turtle populations occupying temporary pond systems move frequently from one pond to another, in part due to differing times of food or water depletion among ponds throughout their activity season (Bowne et al., 2006; Cadi et al., 2004). It can then be assumed that the maintenance of the overall connectivity amongst used ponds is of crucial importance for the persistence of turtle's populations. Apart from measuring pond importance in terms of its topology within a network (structural attribute), this measure also takes habitat suitability into account (functional attribute). Therefore, it can be helpful to optimize conservation effort by prioritizing ponds both in terms of their suitability and contribution to the overall connectivity. Among the different estimated parameters, this is possibly the most relevant for management purposes.

The difference in dPC values between occupied and unoccupied ponds was slightly more pronounced than habitat suitability values alone. This was especially true for the presence-absence of hatchlings and juvenile individuals. In the case of the European pond turtle, these age classes are often referred to as showing a more secretive and selective behavior in terms of habitat selection (Meeske & Mühlenberg, 2004). However, to our knowledge there is no data regarding the effect of pond connectivity attributes on the habitat choices made by younger age classes. Results suggest that pond connectivity may have consequences on the recruitment of turtle's population in the study area. Ponds showing higher node importance values should therefore be a main focus of management actions, by avoiding their destruction and promoting their connectivity.

The second measured parameter, pond coreness, is useful to identify the subset of ponds that are more cohesive in terms of the number of links among them. K-Core values express the robustness of these systems to pond loss. One of the most relevant results of this study was that the two most cohesive pond subsets were those that contained the most important turtle populations: the Longueira and the Pousadas nuclei. This is an interesting result because this parameter is purely structural. It is exclusively based on pond topology within the network. Such as for dPC, this attribute was higher at occupied ponds and, again, this was particularly true for hatchling and juvenile individuals. This suggests that populations with good status tend to occupy more cohesive pond systems. For that reason, this parameter should be used as an additional criterion to prioritize conservation effort on ponds.

Longueira and the Pousadas also contain the largest clique structures, which is also indicative of the cohesive nature of these two pond systems in terms of connectivity. On the other hand, Forninhos and Cruzamento have a medium to high habitat suitability but a low node importance, which means that ponds are weakly inter-connected. The remaining scattered components are very low ranked, according to habitat suitability, node importance and coreness, therefore showing low potential for turtle's presence and connectivity in the actual conditions.

The betweenness index was useful to identify ponds with stepping-stone functions that, in association with cut-nodes, may represent ponds of high conservation importance. This ponds' function have an impact on habitat availability and also on the overall connectivity within patch systems (Saura & Pascual-Hortal, 2007). Although no relationship with turtles' presence was found (results not shown), this parameter is important to identify ponds that are crucial for promoting dispersion among different pond subsets. In fact, among the computed connectivity parameters, this is possibly the one that show a higher long-term importance, allowing genetic flow and recolonization after local extinction events. The Longueira and Forninhos components contain nodes with the highest betweenness values and are also the most extensive components, which makes them the most favourable components in terms of inter-pond turtle movements. These should be the focus of management actions aiming at promoting long distance dispersion of individuals. Regarding cut-node patches their main ecological consequence is that they increase the risk of isolation through the splitting into new smaller components. This is the case of small and scattered components in the south, most of them showing a risk of splitting. At the northeastern region of the study area, the Forninhos component also faces the same risk.

In conclusion, Longueira and Pousadas components were identified as the most suitable for turtle populations, both in terms of habitat availability and connectivity features, showing a strong and well-defined pond network. This is confirmed by field data, as the two areas were found to yield populations with good ecological status. Due to their inner potential both in terms of habitat suitability and connectivity, Longueira and Pousadas seem to have an important role for the species conservation in the study area. These two areas, in particular the Pousadas component, have been less affected by agricultural intensification and the connectivity-based attributes of these two components may in fact reflect a lower impact of human activities. Land management actions that would replicate the spatial structure of ponds found in Longueira and Pousadas would therefore be desirable for the remaining components.

If the main objective of management actions is to expand good status turtle populations into new pond subsytems, the main target should be the Forninhos component. This component is under critical effects of cut-node ponds, showing a greater risk of habitat fragmentation, which is possibly the reason for the lower pond occupancy by turtles. However, it shows moderate habitat suitability and a relatively large clique structure. Therefore, the adoption of adequate management actions, such as the recovery or even the creation of ponds at the right locations, could potentially be successful for expanding the population and improve the population status in this component. Management actions promoting connectivity among the scattered components at the southern region of the study area would be desirable in order to produce a larger component that eventually could be connected to the Longueira's component through the Cruzamento sub-component.

Overall, the results presented here are in line with studies on other turtle species, where connectivity has been pointed out as an important issue for the persistence of turtle populations (Bowne et al., 2006; Lisa et al., 2001). Maintaining connectivity both within and between pond components is an important landscape management and planning approach to species conservation. Management actions should aim the preservation of pond coreness and, ideally, to promote the whole pond system as a network unit (Lisa et al., 2001). This would be accomplished either by maintaining or reinforcing connections, especially with those ponds acting as stepping-stones or cut-nodes. Indeed, ponds acting as stepping-stones or cut-nodes should be the target of differentiated management measures, in order to maintain or even increase connections between ponds.

Concluding remarks

Due to the dynamic nature of the studied pond systems, turtles are often forced to move from one pond to another and, hence, greatly depend on habitat connectivity. Effective management actions should therefore rely on methodologies that are able to evaluate the importance of each pond for maintaining acceptable levels of overall connectivity. As much as possible, these methodologies should be able to take into account some life history specificities of the target species, such as the ability of the species to move through land. In this study we demonstrated the applied value of Graph-based network analysis as a means to estimate parameters that measures different connectivity-related aspects of individual ponds, which may be helpful, as a complement to other relevant ecological information, to optimize conservation efforts.

The European pond turtle has a very secretive behaviour and moreover, as a long-living organism, adequate estimations of life history attributes depend upon to long-term studies. However, it is often the case that the pace of habitat destruction will require urgent conservation actions to be undertaken. This seems to be the case of the temporary pond system in our study area. As supported by our results, network analysis coupled with other modeling approaches such as habitat suitability models, may be the answer in such situations.

Acknowledgments

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6 SYNTHESIS - GENERAL DISCUSSION

“Thus, fragmentation is from the species' viewpoint and not ours.” A. Franklin (2002)

This thesis studies the relationship of habitat fragmentation and connectivity in the local pattern distribution of wild species. The case studies are based on peer-reviewed articles, in the context of geographic modeling approaches, and have contributed to the understating and prediction of some aspects of pattern-process interaction. In the presented studies the strategies to gain insights of pattern-process assessment was governed by process description, pattern detection and analysis as well as simulation and generation scenarios. It was assesses for four intraspecific population processes - distribution, reproduction, mortality and dispersion. The methodologies may contribute to some levels of spatial transference. Some of the case studies achieved results that may translate into spatial standards and form theses for management and conservation planning.

Assuming that biodiversity is an economic resource, intended to ensure exploitation of resources in the long term, it is necessary to preserve and to explore it. Therefore, it is essential to incorporate the economic implications of the habitat fragmentation. The general conclusions confirmed by the recent published articles are: (a) The assessment of fragmentation depends on the scale of analysis (Riitters et al., 2000) and (b) that the major factor in determining species persistence is the total amount of available habitat (Fahrig, 2003; Fahrig & Rytwinski, 2009). In areas becoming high fragmented, it is important to assess the potential resilience of species to the lost of space and connectivity.

In fragmented scenarios the spatial pattern of the remaining areas becomes more important to maintain viability. As the total area of available habitat decreases, many important processes to species resilience are affected. According to our work and the cited studies, the habitat abundance and well connected are issues of relevant importance. Dispersion is a key factor of the species maintenance. Connectivity is also scale dependent, and species seem to respond to multivariate habitat heterogeneity at multiple scales. Connectivity characteristics change substantially if we are concerned of aquatic environments or other moving elements, such as nutrients or energy flow.

The concept of ecological threshold may accommodate a useful theoretical framework to the fragmentation process. It is clear that ecological processes of spatial disturbances (alter drivers) have a trigger effect and subsequently affects patterns that are associated with the habitats being disturbed. Disturbances can reach a point at which there is significant change in the habitat quality, affecting the species resilience. The analysis of threshold effects is related to spatial nonlinearities dynamics of responses and controlled by multiple complex factors of difficult validation (Groffman et al., 2006). This spatial nonlinearities dynamics of responses makes it more difficult to identify specific thresholds. It is still very difficult to predict when a system is nearing at threshold. Spatial nonlinearities factors and ecological threshold are challenging research issues.

Human based stressors (i.e., habitat fragmentation) operate at different spatial and temporal scales, so the indication of an approaching threshold should contain series of variables and their spatial distribution (Groffman et al., 2006). The interactions among multiple drivers as sources of spatial pattern generator remain poorly understood (Turner, 2005). Therefore, it is very important to address methodologies to monitoring how habitat is approaching a threshold associated to fragmentation process. Geographic modeling can be useful to identifying the critical thresholds in a habitat. Identify ecological process, by assessing the parameters of habitat conditions. Monitoring sudden changes of connected or disconnected behaviors.

The threshold effects have consequences on population size or persistence. However, spatial threshold values (breaking points) are associated to each species resources needs and historic evolution (Fahrig, 2002). The underlying conditions and mechanisms are key aspects of threshold occurrence. Operational tools and available information about the threshold occurrences is fundamental to management decisions. One of the strengths in the threshold concepts is the possibility of using the ‘‘adaptive management’’ view that enhances a constant re-evaluated process. Indicator species or species behavior could be used as proxies to forewarn managers. To take actions into minimize the probability of crossing ecological thresholds, as used by Sasaki et al., (2011).

According Chetkiewicz et al., (2006) the fundamental issues that hinder the development of connectivity studies, is the lack of knowledge about the habitats selection and the drive mechanisms of the species, in other words; the relationships between pattern and process. Forecasting future relationships between patterns-process remains an exigent task in which the suite of drivers and their interactions must be considered. In habitat fragmentation experiments, it has often been difficult to separate the effects of habitat reduction and isolation. All these questions are in one way or another interrelated (Wu et al., 2003; Wu et al., 2004).

Mobility is a matter of the utmost importance for understanding the effects of habitat fragmentation on the species population dynamics and distribution. In practice, not all species exhibit the same behavior to fragmentation, differing in sensitivity to habitat fragmentation (Vos et al, 2001; Fraser & Stutchbury, 2004). Our intention is to affirm that the interconnection space is an absolute insurance to all species, which largely represents a challenge for planning. Species respond differently to fragmentation process, with implications on other species patterns (Rutledge, 2003). According to Franklin et at. (2002), fragmentation should be evaluated by the species perspective; the same process can have different meanings and impacts. It is expected that interpretation and the conceptual meaning of space may differ between species and particularly in relation to the human perception.

How do spatial metrics measure the effects of habitat fragmentation in ecological processes? The use of metrics is assumed to have great potential for expansion. The use of metrics seems to be the most effective form to assessing and monitoring landscape scene. Metrics may have restrictive proprieties, but provide a meaningful way to archive planning objectives (Botequilha & Ahern 2002; Rutledge, 2003). The systemic integration of indicators allows us predict and model fragmentation development. The development of pattern metrics has stabilized, but is often used to relate landscape pattern with the ecological responses (Turner, 2005). Nevertheless, understanding the ecological relationship of pattern-process is distinct from quantification of pattern and the use of an indicator may quantify one process and not another.

In practical terms, there is no single metric, which could describe and evaluate spatial matrix complexity. An important conclusion of the simulation modeling is that linear relationships among landscape metrics are not generally valid as it is assumes in many studies (Fortin et al., 2003; Turner 2005). Usually the measurement of spatial patterns receives much attention by the development of metrics. It is also important to consider the relationships between ecological processes and spatial patterns. While certain metrics are useful in specific cases, most metrics should only be used to describe pattern, and should not be an end itself (Rutledge, 2003; Li & Wu, 2004).

Overall metrics do not serve as useful tool to quantify local patch fragmentation effects. The strength of landscape metrics is in their straightforwardness, but their weakness is the lack of explicit relationship to ecological processes and meaning (Vos et al., 2001; Li & Wu, 2004). Nevertheless, the metrics allow us to assess the conservation status and to develop instruments between sciences and decision-making, when they are complemented (Rutledge, 2003). A positive approach is selecting landscape metrics by “biologically meaningful” criteria (Lawler & Edwards, 2002). By plotting a map, the obtained metrics is very useful to stratify sites or identify higher-order information (Turner, 2005).

It is general acceptable that the tools to build simulation models are growing, but there are still limitations. Limitations from information lacking (quantitative and qualitative data), that bring appropriate knowledge to the objectives. The lack of data and its adequacy means that the models are based on self-governing parameters, which influence and, in some cases, determine the spectrum of results. Conceptual limitations that hinder the models, like functional aspects associated with the species mobility and their interaction with the space. Some of the most sensitive issues in the construction of the geographic models are related to their calibration under real conditions, and also to testing and validation the conditions.

In the presented case studies the strategies to gain insights of pattern-process assessment was governed by process description, pattern detection, pattern analysis but also simulation and generation scenarios. The proposed methods in these works were guided by the applied robust spatial technique analysis. It was intentional to conduct research that created the knowledge methodologies and techniques to incorporate geographic modeling. The use of SDMs models reflects the former approaches: (i) a process-based approach in mechanistic process-description (ii) pattern-based approach. Some of the techniques are relatively unused, but prove helpful in the application and provide visual presentation information. Point pattern analysis shows very interesting properties to evidence pattern distribution, with relatively few resources and exceptional simplicity. This method based on discrete point data space was important and served several purposes (i.e. evidences of hot spot; time-series sampling, etc).

Network analysis (graph) provided advance properties in functional connectivity analysis. The network analysis provided a very flexible conceptual model, helping the description of configuration and composition and relationship between pattern-process (Dale & Fortin, 2010). This is a developing technique with future exploring resources (i.e. visual interpreting proprieties). In many planning actions, there can be a sufficient map of the produced graph and the spatial configuration of habitat it describes. Network analyses have sufficient qualities to engaging researchers and stakeholders to support the decision-making in planning process. Geographic models, such as those offered by graph theory, may provide synthesis information on the relative importance of connectivity, habitat condition attributes (i.e. quality), spatial patterns and alternative scenarios, which are important features. In the presented case study (chapter 5) it was shown how spatial graph properties might be used for description and also as to specific hypotheses test.

The future challenge is identifying and validating relevant environmental predictors, to use them in ecologically realistic modeling of fragmented scenarios. These tasks need more systematic data with different spatial and temporal resolution. One promising research direction is to detect and generate surfaces of species mobility using monitoring data and environmental predictors. One other promising research direction is in inverse modeling, to generate processes as source of patterns that will be used to compare with observed patterns (Schröoder & Seppelt, 2006). According to Turner (2005), improve the "*mechanistic understanding of the relationships between pattern and process*".

So far, the model developers' intent was to explain distribution patterns or, in some cases, generates former hypotheses. Now, we may consider the existence, dissemination and the application of a new generation of geographic models: geographic models, base on probabilistic and stochastic assumptions, governed by new levels of spatial information and automated workflows. The information gained can then be used to evaluate and decide between different management actions, resulting in more effective use to conservation resources and larger gains in conservation outcomes. Although, Elith & Leathwick (2009) state that it is expected that modeling advances might emerge as an outcome of new forms of theory, concepts, and practice, rather than from improved methods.

6.1 Concluding remarks

The presented studies have contributed to the assessment of factors that explain variation in species local pattern distribution. There are still many open questions about the mechanisms of relationship between habitat fragmentation and implications in species pattern distributions. As our work and understanding evolves, more questions and peculiarities will shape the relationships. Future research and modeling should incorporate fragmentation directly, by identifying and understanding the relationships between patterns and processes, in particularly those that result global climatic changes. It seems a promising research field to understand the interactions and crossing contingent effects of multiple disturbances.

As a simple perspective, besides the existence of very exact data about spatial distributions, a landscape manager and planner can model habitat fragmentation if he: (i) uses habitat types distribution, (ii) selects habitat suitability to the target species, and (iii) associates species to an indicator of fragmentation sensitivity, all reasoned on knowledge about species threshold of dispersal distances and area requirements.

In terms of conservation planning the important question is whether species are still resilient to habitat fragmentation or have pass the viability threshold, the turnover, or shift point. In future scenarios, it is expected additional needs and new forms of interspecific processes will emerge. Geographical modeling can support elements identification and implement the planning and conservation actions, based on progressive methodologies and new visual representation forms.

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CONSIDERAÇÕES SOBRE A FRAGMENTAÇÃO TERRITORIAL E AS REDES DE CORREDORES ECOLÓGICOS

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RESUMO

Ao longo deste artigo são abordadas as diversas dimensões do conceito de fragmentação territorial bem como os instrumentos de análise espacial no seu estudo e avaliação. São igualmente afloradas as metodologias para a definição territorial de redes de corredores ecológicos. A utilização de indicadores de composição e configuração permite a monitorização dos efeitos da fragmentação territorial, causados pelas diferentes ações do homem na matriz territorial. Indicadores, que caracterizam as manchas territoriais tendo em conta a dimensão, a forma e o grau de conectividade das manchas do habitat na resistência e promoção dos movimentos das espécies de fauna e flora. O planejamento de redes de corredores ecológicos tem por objetivo minimizar os efeitos negativos da fragmentação territorial. A modelação geográfica e as metodologias de estatística espacial apresentam-se como um meio na identificação de soluções e alternativas de redes de corredores ecológicos para a articulação territorial.

Palavras-chave: Biodiversidade; Corredores ecológicos; Fragmentação; Planejamento; Espécies.

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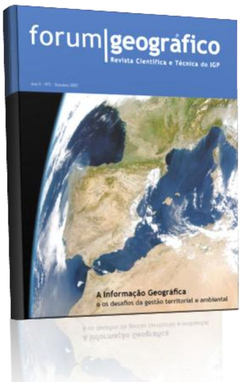

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Artigo
38

Biological and Geographical application tool

Miguel Pereira

Abstract

Monitoring and species identify is an essential step to natural resources management. Among these, biological resources aim special concern because data availability is highly limited by a number of sampling logistic constraints and catalog. As a matter of fact, data availability is one of important limitation to knowledge and, as a consequence the development of a new concept in natural resources. Data organization in digital format is a common practice in our days, and has the power to contribute to timely decisions process. Digital support and software tools are increasingly required in knowledge base systems. With this article it is our aim to present a Biological and Geographical application tool (BioGeoDB). We intend to show the application potentialities uses, the developed model and articulation between subsets. The developed application use a biological database associated with a desktop map environment. Application generates datasets reports and thematic or modeling cartographic maps display. BioGeoDB has been developed with the purpose of making compatible different datasets, derived fro m fieldwork studies of biodiversity monitoring programs, and also published studies. Until application development data storage was been recorder into fragment system, with no updatable structure and missing information consequences.

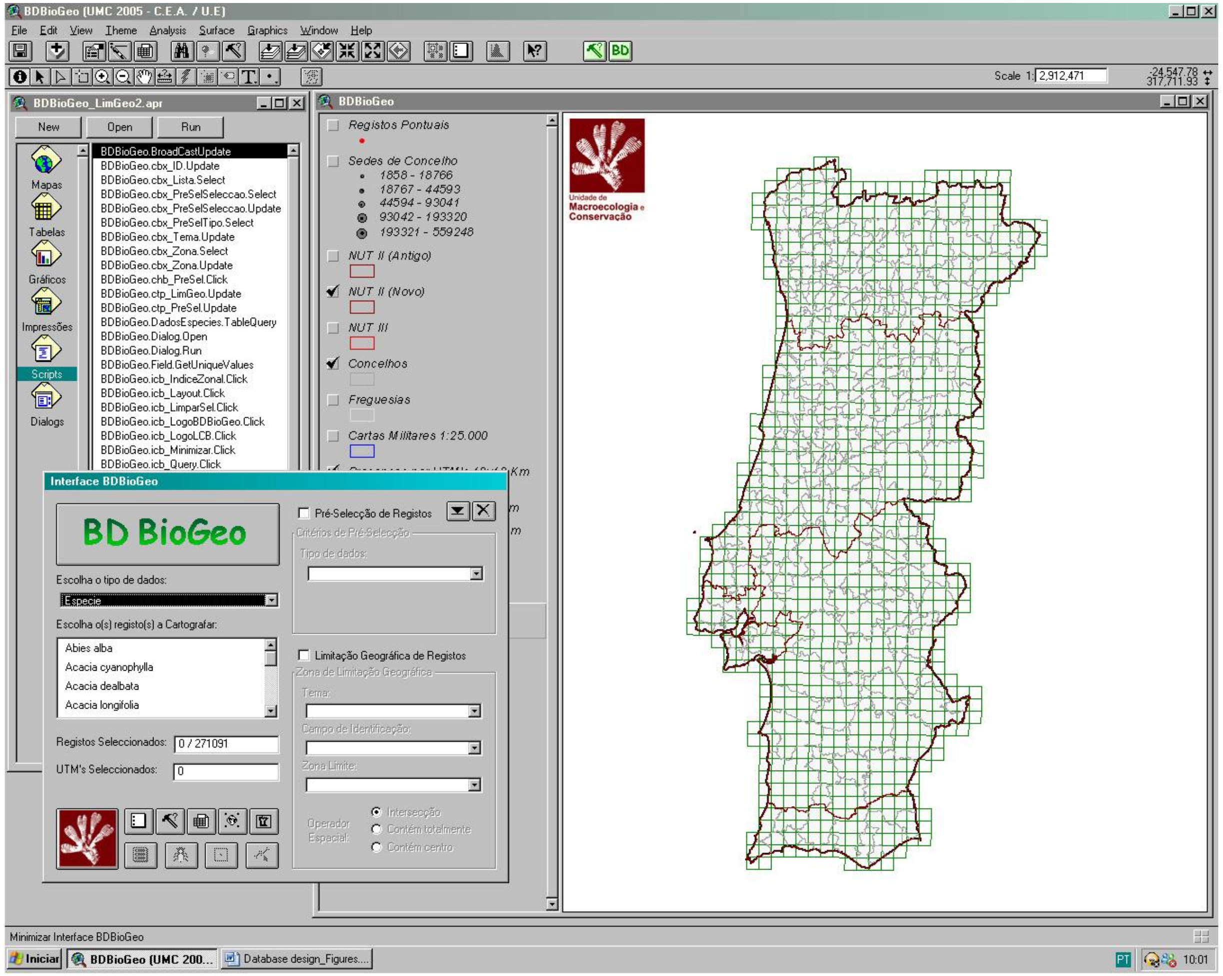

Figure 2-3. GIS interface menu where the users chosen species selections. Selections can be execute from different attributes (e.g. name, family, distance, administrative boundary, etc)

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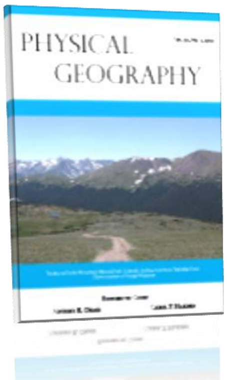
PHYSICAL GEOGRAPHY (ISSN 0272-3646)



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EFFECTS OF THE ALQUEVA DAM RESERVOIR ON THE DISTRIBUTION OF STEPPE BIRDS

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Abstract: The effects of the Alqueva Dam reservoir on the distribution of steppe birds (before and after flooding) was quantified using point-pattern analysis. Sampling points from the dam biological monitoring program, which included data from winter and breeding seasons, were used. To quantitatively assess spatial patterns, the point-pattern was tested using a sequence of statistical methods. Autocorrelation was measured using Ripley's L-function and O-ring, and was validated by a complete spatial randomness null model in the birds' suitable habitat. A gradient surface of probabilistic abundance was developed with a Kernel Density Estimator and compared with the Kappa Index of Agreement. The results indicate a decline in the absolute abundance of steppe birds in both seasons, but it is more evident in the breeding season. The results also show an increase in the mean distance between the point surveys, some evidence of a global trend toward the northeast, a decrease of patch values, and a disaggregation of continuous patches. [Key words: Alqueva Dam, monitoring, point-pattern analysis, pseudosteppes, steppe birds.]

INTRODUCTION

In recent decades, there has been growing interest in spatial issues in biogeography, expressed by research in spatial pattern analyses (Perry et al., 2002). The species themselves tend to be nonrandomly located in space, as we expect from live individuals and communities as a sign of a regular modeling (Ebdon, 1985; Legendre, 1993; Perry et al., 2002; Bergon et al., 2006). In most cases, the pattern of living species is related to the habitat or to a random selection over clumped habitat patches (Lancaster and Downes, 2004). The spatial pattern of species distribution is related to different ecological processes (Bergon et al., 2006). Understanding ecological processes starts with the identification of spatial patterns, spatial forces, and dynamic interactions (Legendre and Legendre, 1998; Davis et al., 2000; Fortin et al., 2002). In fact, spatial pattern discovery allows the testing of different underlying ecological processes and changes in recognizable structures, resulting in a spatial autocorrelation or dependency relationship (Bergon et al., 2006).

The spatial structure of an ecosystem plays a key role in its dynamics (Goreaud and Pélissier, 2003), and spatial disturbance may result in different future evolution patterns. Natural and human disturbances can reshape communities and species distributions, such as in the case of dam construction; the consequences of a disturbance can therefore be tested and measured using sample data and spatial pattern analysis (Liebhold and Gurevitch, 2002).

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Physical Geography, 2009, **30**, 1, pp. 43–63.
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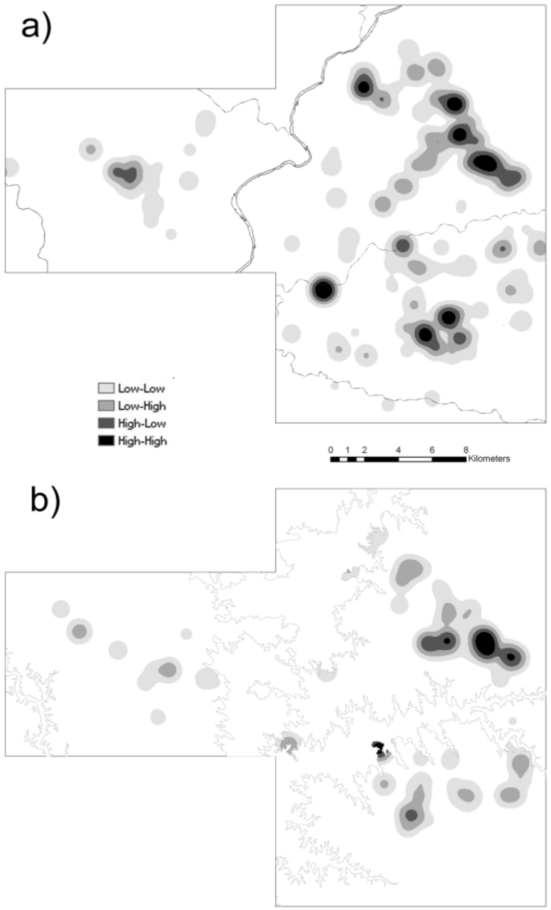

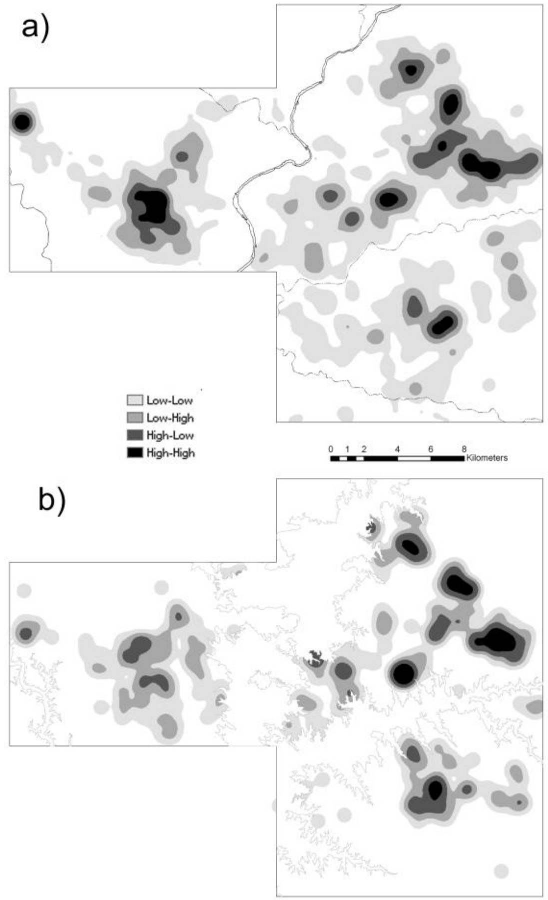

Figure 3-8. KDE of reshaped map for 95% of the bird winter season population in four classes of densities a) in T_0, the solid line represents the main river and the dash lines the secondary rivers; b) in T_1, the solid line represents the flooding water level.

Figure 3-9. KDE of reshape map for 95% of the birds breeding season population in four classes of densities a) in T_0, the solid line represents the main river and the dash lines the secondary rivers; in b) T_1, the solid line represents flooding water level.

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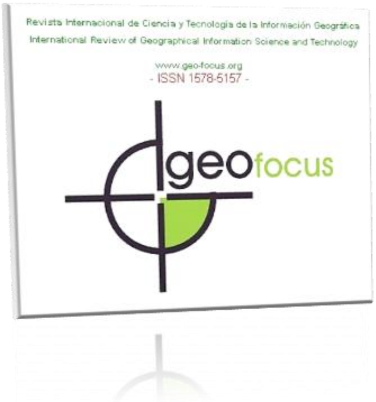

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THE ROLE OF HABITAT CONNECTIVITY ON ROAD MORTALITY OF TAWNY OWLS

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ABSTRACT

Research of habitat fragmentation has revealed a large number of constraining effects, 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 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 ACIDENTES RODOVIÁRIOS

RESUMO

A investigação sobre a fragmentação dos habitats tem revelado importantes constrangimentos 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 acidente em estrada. 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 mortalidade. Os resultados revelam evidências de fragmentação do habitat e o aumento da ocorrência de acidentes. Os resultados permitem

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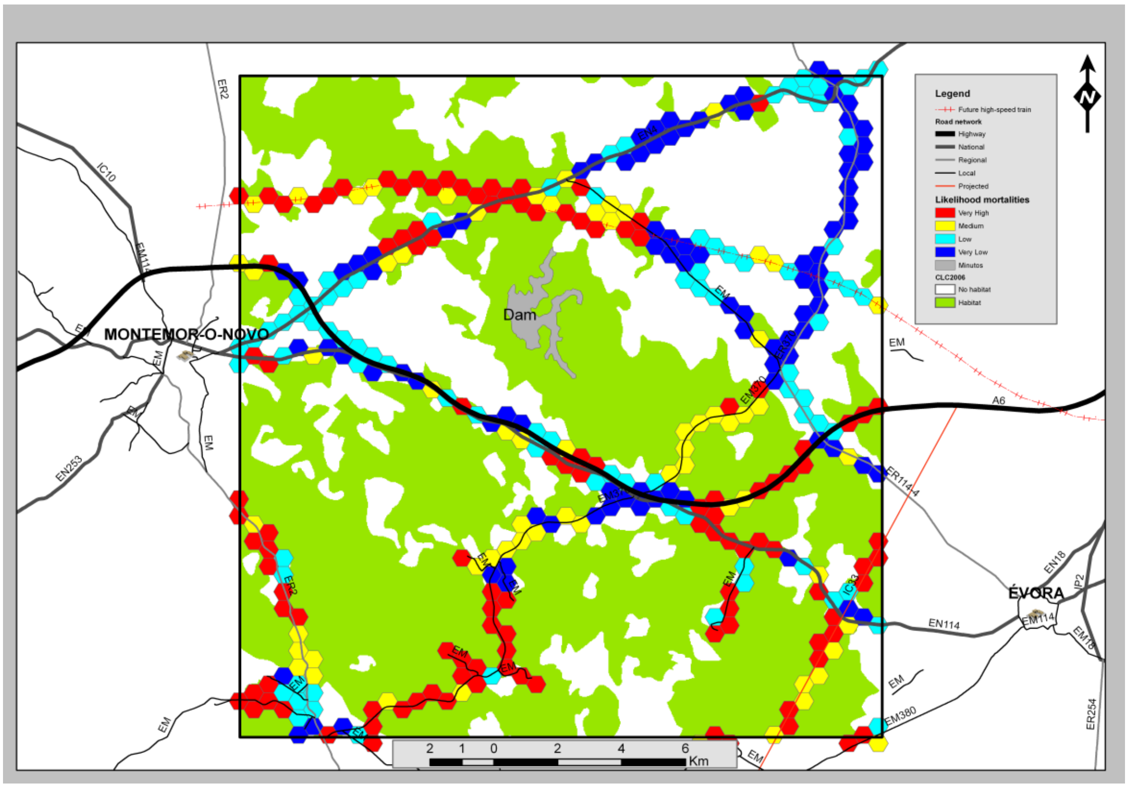

Figure 4-8. The generated spatial model of likelihood mortalities occurrences shows problematic areas of the impact of the existing and future infrastructures.

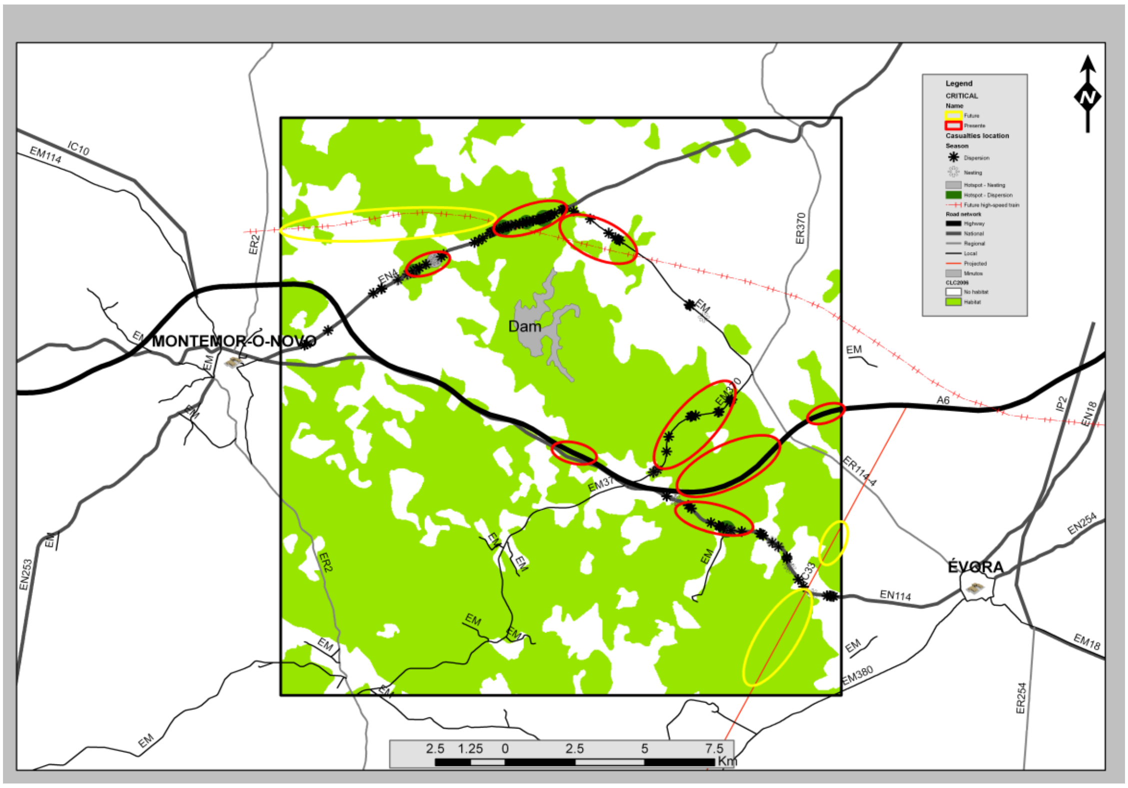

Figure 4-9. The present and the near future critical areas of infrastructures impact.

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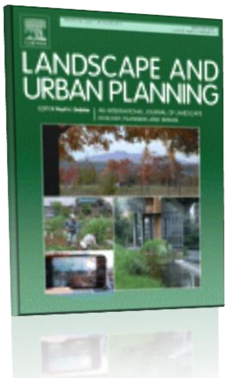

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Using spatial network structure in landscape management and planning: A case study with pond turtles

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A B S T R A C T

Connectivity is currently a central issue in landscape management and planning for the conservation of wildlife species occupying scarce habitat patches. In recent years, this issue has increasingly been addressed using methodologies based on spatial network analysis. Here, we propose a hybrid approach based on network analysis tools and empirical habitat suitability models to integrate connectivity on decision-making. The study is focused on a pond system used by the European pond turtle, *Emys orbicularis*, in a coastal area in southwestern Iberia. The main objective of the study was to illustrate how the output of graph models may be useful to guide habitat management and planning. We assessed ponds according to three complementary structural and functional properties derived from a graph model: (1) pond importance as measured by the sensitivity of the overall connectivity to each pond loss, (2) pond coreness, used to identify the most cohesive pond subsystems and (3) pond betweenness, which measure the importance of ponds as stepping stones. The graph model took into account a resistance-to-movement surface, the maximum traveled distance and a habitat suitability model based on field sampling. Pond importance and coreness were shown to be positively related to occupancy, especially by turtle's youngest age classes, suggesting an important contribution of connectivity attributes for turtle populations. We discuss the ways these pond connectivity-related attributes may be helpful to assist and optimize management efforts for the conservation of the European pond turtle in the study area.

1. Introduction

The increasing fragmentation of habitat is a major consequence of human actions in the landscape. An important result of habitat fragmentation is the loss of connectivity between habitat patches used by species. According to Taylor et al. (1993) landscape connectivity "is the degree to which the landscape facilitates or impedes movement of organisms among resource patches". Species need connectivity to obtain the basic resources to ensure survival and the diffusion of genes flow (Pardini et al., 2005). Fragmentation acts directly or indirectly on home range sizes, breeding success, productivity areas and mobility of species (Malanson, 2002; Nikolakaki, 2004). Habitat fragmentation may reduce a species' geographical distribution and limit the viability of local populations (Chetkiewicz et al., 2006).

Conservation planning and landscape defragmentation are important instruments in policy and practice to promote connectivity (van Bohemen, 1998). In fact, in the context of conservation research, a major concern has been on habitat connectivity, especially the design of ecological habitat corridors (Beier et al., 2008; Chetkiewicz et al., 2006). In order to identify the relevant habitat attributes (e.g. size, connectivity, ecological function) to be accounted for in conservation actions at the landscape level, information about specific ecological processes of target species is needed (Bowne et al., 2006). The identification of habitat attributes provides important guidelines for developing connectivity models. A simple approach is through the use of habitat models describing relationships between spatial patterns of a given species' attribute (e.g. distribution of individuals) and a set of habitat or landscape attributes (Guisan and Zimmermann, 2000).

One way of assessing the structure and the behavior of a spatial complex system is to identify its properties on a graph model (Green et al., 2007). This approach is especially useful to address questions related to network structure, objects centrality, their interactions and flow efficiency (Green et al., 2007). A graph provides a simple method of representing habitat patches within a

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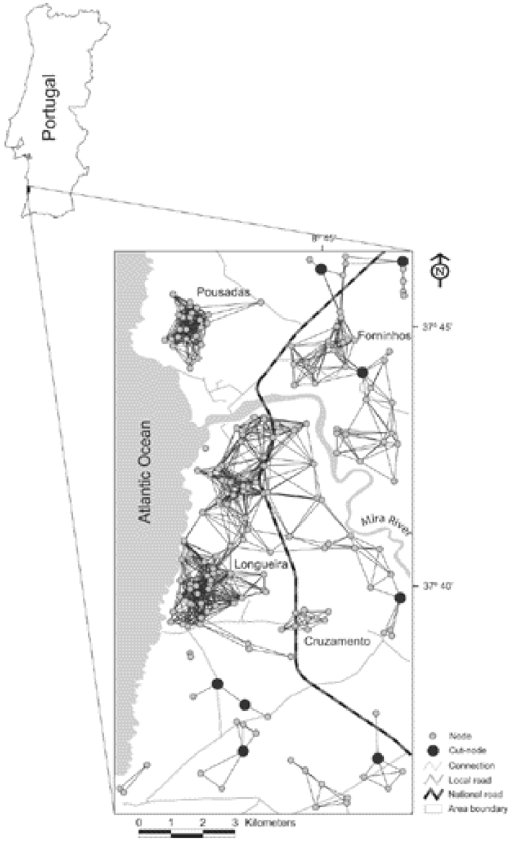

Figure 5-1. Study area with the main natural barriers (Atlantic ocean, salt river and asphalt road network) online at: http://maps.google.pt/maps/. The pond network (with 11 components) and respective graph connections for a threshold distance of 2000 m. Larger black dots represent cut-nodes, which suggest a greater risk of connectivity disruption in Forninhos and in the scattered components of the southern region of the study area.

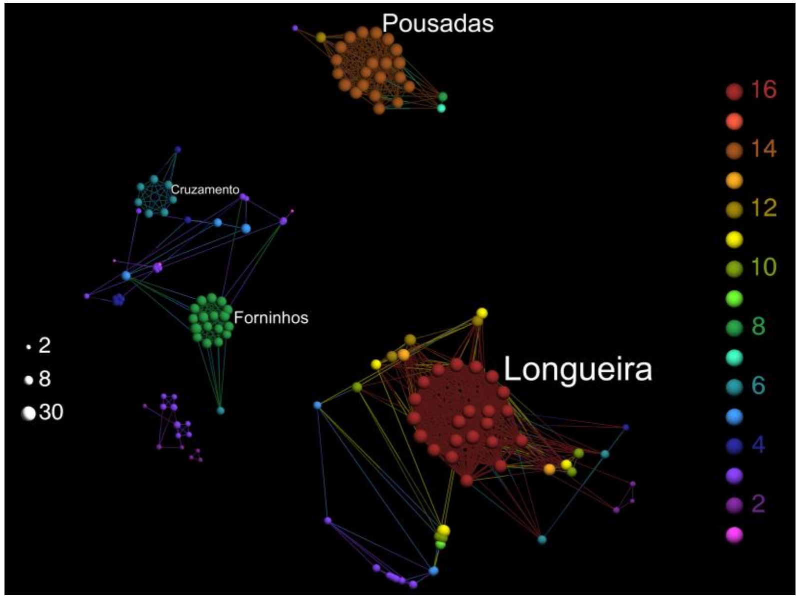

Figure 5-4. k-Core decomposition shell index of the 191 ponds. The dots' positions are based on polar coordinates; dot colors between warm–cold express the coreness value (high–low, respectively), and size represents the number of links per patch (e.g. red nodes in Longueira are the central ones in this component): composed by a 16-clique and other smaller cliques. Peripherical nodes for each component are positioned close to their neighbors in higher cores.

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