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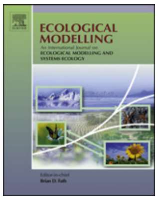

Estimating the influence of overhead transmission power lines and landscape context on the density of little bustard *Tetrax tetrax* breeding populations

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ABSTRACT

Collision with conductors and earth cables is a known impact generated by transmission power lines, however there is virtually no information on how these infrastructures might affect bird distribution in a landscape context. With this work we specifically hypothesise that transmission power lines may affect the occurrence of a threatened bird, the little bustard (*Tetrax tetrax*). To test this hypothesis we used a Stochastic Dynamic Methodology (StDM), analysing the effects of power lines in a landscape perspective and simulating population trends as a response to power line installation and habitat changes induced by agricultural shifts in southern Portugal. The data used in the dynamic model construction included relevant gradients of environmental conditions and was sampled during the breeding seasons of 2003–2006. Transmission power lines were significantly avoided by the little bustard and the developed StDM model showed that the distance to these utility structures is the most important factor determining breeding densities in sites with suitable habitat for the species, which possibly leads to displacement of populations and habitat fragmentation. The model simulations also provided the base to analyse the cumulative effects caused by the habitat degradation that can ultimately lead to the extinction of local populations. Within priority conservation sites, the dismantling of existing transmission lines should be considered whenever possible, in order to ensure adequate breeding habitat. The model is considered useful as an auxiliary tool to be used in environmental impact assessments, management and conservation studies.

1. Introduction

From the middle of the last century there has been a generalized expansion of the power grids, as a result of increasing consumption of electricity, mostly motivated by economic growth. The development of new electric production facilities, such as wind and solar farms, normally installed at a considerable distance from the energy users, and the need to implement transnational energy markets are presently the most important factors driving the construction of new overhead high tension power lines (REN, 2008). As a result, power lines are a common element in the landscape, crossing a significant number of habitats, including priority areas for the conservation of birds. The impact of these structures has been almost exclusively attributed to the direct effects of mortality by collision of birds with phase conductors or earth cables. In open-country, overhead high tension power lines, because of their large size and prominence, might also constitute a barrier effect for bird species (Ballasus and Sossinka, 1997; Pruett et al., 2009). Additionally, the presence of electric poles in open-country habitats is beneficial to some raptors by providing perches with commanding views of hunting areas (Stahlecker, 1978; Graul, 1980; Lammers and Collopy, 2007). Therefore, the hunting efficiency might be greater and predation pressure is likely to be higher for some more vulnerable prey (Plumpton and Andersen, 1997; Lammers and Collopy, 2007). However, virtually nothing is known about how these structures influence open-country species in their habitat requirements, use or avoidance (Pruett et al., 2009).

Although South European landscapes have evolved over thousands of years with a gradual and increasing role played by human activity (Naveh, 1998), recent agricultural intensification, habitat

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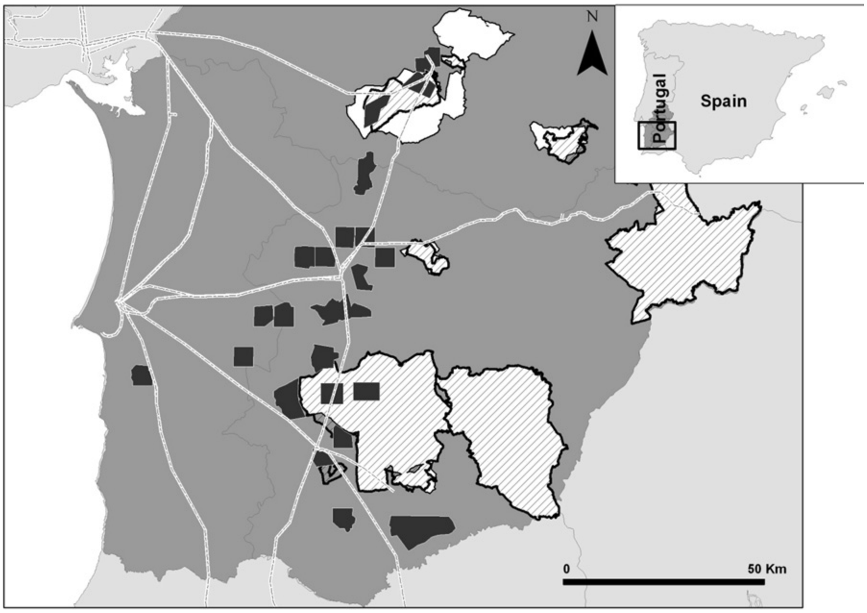

Fig. 1. Location of the study area in the Iberian peninsula. Areas in white represent Important Bird Areas (IBA), while areas filled with black lines stand for Special Protection Areas (SPA). Dark grey areas represent the studied little bustard nuclei. Dotted lines stand for the transmission lines that cross the region.

loss and degradation, quickly induced profound changes in landscape structure (Baudry et al., 2000). Many wildlife species have been unable to adapt to such radical changes, such as the little bustard (*Tetrax tetrax*), a medium-sized grassland bird. The stronghold population of this threatened bird (Goriup, 1994) is located in the Iberian Peninsula, with more than half of the world's population (Schulz, 1985; BirdLife, 2009). It is considered a priority species for conservation under the European Bird Directive (2009/147/CE) and numerous Special Protection Areas (SPA) have been designated aiming for its protection. Power lines also represent a threat, since this species is among one of the most susceptible birds to collide with overhead power lines (Bavenger, 1998; Janss, 2000), causing an estimated annual mortality, of over 1.5% of the Portuguese national population (J.P. Silva, unpublished data).

Along the yearly cycle the little bustard benefits from the extensive cereal farming rotational agro-ecosystem (Silva et al., 2004), depending mostly on fallow lands during the breeding season (e.g. Martínez, 1994; Morales et al., 2006). The vicinity of anthropogenic factors such as inhabited houses or roads is avoided (Suárez-Seoane et al., 2002; Silva et al., 2004; Osborne and Suárez-Seoane, 2006), although there is no information regarding how high tension power lines influence the little bustard's distribution. This is an important conservation issue since vast areas of potential breeding habitat for the little bustard are crossed by hundreds of kilometers of transmission power lines, including Portuguese steppic SPA. New high tension power lines are being planned to cross important steppic habitats in Portugal (REN, 2008) and adequate information is needed to correctly assess and minimise its impacts on this threatened grassland bird.

In the present study we hypothesise that the little bustard avoids the proximity of high tension power lines, thus population densities are expected to decline near these structures. To test this, we evaluated the importance of power line location on little bustard male densities, also taking into account other factors known to affect male occurrence such as the proportion of favourable habitat and distance to other anthropogenic structures (e.g. roads and inhabited houses). We further modelled the population trends of this grassland bird in face of different scenarios of habitat changes and power lines installation using a Stochastic Dynamic Methodology (StDM). The StDM provides a mechanistic understanding of the holistic ecological processes, and is based on a statistical parameter estimation method. In fact, statistical patterns of ecological phenomena are considered emergent indicia of complex ecological processes that reflect operation of universal law like mechanisms (Cabral et al., 2008; Santos, 2009). The StDM was successfully applied and validated in other relevant conservation scenarios (e.g. Santos and Cabral, 2004; Santos et al., 2007, 2010).

2. Methodology

2.1. Study areas

Fieldwork was carried out during the national breeding census in Alentejo (*Project LIFE02NAT/P/8476*: *Conservation of the little bustard in Alentejo*), which is the most important region for the species in Portugal, concentrating between 90 and 95% of the national breeding population (Silva et al., 2006). The census consisted in estimating the breeding male density at a network of sampling points for a total of 81 sites. These sites were previously selected in accordance with the following criteria: (1) within steppic Important Bird Areas (IBA; Costa et al., 2003) and (2) random sites with an area of approximately 2500 ha within quadrates of a 10 km × 10 km UTM grid that represent over 40% of potential area for the little bustard (i.e. agricultural or pastoral land use), based on the Land Cover Corine 2000 land use map. For the purpose of the present study, from these 81 sites we selected the ones in the vicinity of transmission lines, up to a maximum distance of ca. 15 km. This resulted in a sample of 23 sites (from which four are within IBA or SPA) (Fig. 1). The study areas covered an overall area of 75,216 ha, with a mean area of 3272 ha per site. These areas contain pertinent gradients of the landscape, considering the environmental changes (agricultural intensification, afforestation and power lines installation). This is of particular importance when it comes to the comprehension of the little bustard's population responses.

Simple and double circuit transmission power lines were studied, covering different voltages: 150, 220 and 400 kV. The height of the towers varied approximately between 30 and 60 m high.

2.2. Little bustard counts

Little bustard censuses were based on breeding male estimates, since females and non-breeding males are not conspicuous enough to be detected in workable numbers (e.g. Silva et al., 2006).

Fieldwork was planned in advance with the aid of topographic maps 1:25,000, to ensure a network of sampling points spaced by 600 m between them, along dirt tracks, avoiding the proximity of inhabited houses and paved roads, ensuring distances of at least 300 m from these structures. A mean density of one sampling point every 111 ha was achieved. Each point was surveyed by one or two observers, using binoculars with a 8× or 10× graduation. The counts were carried out during the first three hours after sunrise and the last two before sunset (Schulz, 1985; Jiguet and Bretagnolle, 2001), the periods where most breeding males are active and conspicuous. Males were counted at each sampling point for a period of approximately 5 min within a radius of 250 m. Sampling points were carefully accessed by car to ensure that males were detected in case they were flushed. IBA and SPA were counted two or three times within the same season, spaced by at least 15 days between counts. All other study sites were counted one single time. Overall, 934 counts were performed during the 4-year-study period. Thereafter, the little bustard density is expressed as the mean number of males recorded by sampling point. The linear distance of each sampling points from the closest transmission power line ranged from 6 to 21,190 m.

2.3. Habitat characterization

Survey points were divided into eight quadrants for evaluating which land use was the predominant one. The following land uses were found in our study sites (Table 1): fallow land, ploughed land, cereal crops, vineyards and olive groves, pine and eucalyptus plantations, diverse legumes, sunflower plantations and montado (cork and holm oak). The spatial fraction occupied by each land use was expressed in percentage. After inserting the field data on a Geographic Information System (GIS), other variables were calculated, namely the meters of paved road, track, railway, and the distance to nearest urban centre and overhead high tension power line as well as the number of buildings within the survey point (radius of 250 m).

2.4. Data analysis

2.4.1. Determining the little bustard response to the environmental variables

Since the ultimate goal is to produce simulations that permit the creation of more realistic scenarios, the applicability of a Stochastic Dynamic Methodology (StDM) was tested. The StDM proposed is a sequential modelling process initiated by a multivariate conventional procedure. However, the fact that the data we considered consisted of *n* independent variables, does not automatically imply that all variables have a significant effect on the magnitude of the dependent variable. Therefore, the regression model with the maximum likelihood was selected using the Akaike Information Criteria (Akaike, 1974) (AIC). The AIC measures a trade-off between a small residual sum of squares (goodness-of-fit) and model complexity (number of parameters). The fit of each candidate model was assessed using the value of AIC corrected for small sample bias (AICc, Hurvich and Tsai, 1989) and the models, in all possible combinations, were compared using the Akaike weights (AiCc wi, Anderson et al., 2000). The regression model selected was then subjected to an ANOVA and each variable was inspected for significance. Although the lack of normality distribution of the dependent variables was not solved by any transformation (Kolmogorov–Smirnov test), the linearity and the homoscedasticity of the residuals were achieved by using logarithmic transformations ($X' = \log[X + 1]$) in each side of the equation, i.e. on both the dependent and independent variables (Zar, 1996). The lack of substantial intercorrelation among independent variables was confirmed by the inspection of the respective tolerance values. All the statistical analysis was carried out using the statistical software Systat (version 8.0®, Cranes Software International), SMATR 2.0® (Falster et al., 2006) and SAM 3.0® (Rangel et al., 2006).

Table 1
Specification of the key variables considered in this study.

Variables	Specification	Model codes
Variables		
Indicator		
Male density	Number of males by point count	Tetrax
Independent variables		
Other land uses	Percentage of area occupied by other land uses	Other land uses
Fallow land	Percentage of area occupied by fallow land	Fallow land
Ploughed land	Percentage of area occupied by ploughed land	Ploughed land
Cereals	Percentage of area occupied by cereals	Cereal
Vineyards and olive groves	Percentage of area occupied by vine and olive	Woody cultures
Pine and eucalyptus plantations	Percentage of area occupied by pine and eucalyptus	Forest
Diverse legumes	Percentage of area occupied by legumes	Legumes
Sunflower plantations	Percentage of area occupied by sunflower	Sunflower
Cork and Holm oak	Percentage of area occupied by Cork and Holm oak	Montado
Distance to the nearest high voltage power line	Meters from the point count to power line	Power line distance
Road network	Meters of road in the area	Road
Power lines network	Meters of power lines in the area	Power line meters
Tracks network	Meters of power lines in the area	Tracks meters
Railway network	Meters of railway in the area	Train meters
Distance to the nearest urban area	Meters from the point count to near urban area	Urban meters
Area occupied by houses in the area	Percentage of area occupied by houses	House area

2.4.2. Conceptualisation of the model

Since the StDM procedure was based on a very complete database, covering the relevant gradients of disturbance (namely induced by power lines installation, land uses and road and railway developments), over space and time, the significant partial regression coefficients were assumed as relevant holistic ecological parameters in the dynamic model construction (Santos and Cabral, 2004). In a holistic perspective, instead of single parameters, our focus is the global influence of the environmental variables selected (rated by the respective partial regression coefficients) that are of significant importance on several complex ecological processes, not included explicitly in the model but statistically related with the little bustard occurrence and density. For the development of the dynamic model the software STELLA was used (version 9.0.3.®, Isee Systems, Inc.).

2.4.3. StDM performance and simulations

For validation purposes, a set of independent environmental data (94 points), not used to estimate the parameters of the regression model, were applied (by inserting the environmental data into the StDM model) to confront the simulated values of the little bustard densities with the real values recorded in those situations. The environmental data were grouped previously in five “landscape groups” using the k-means clustering, which evaluates each observation moving it into the nearest affinity cluster (MacQueen, 1967). These groups were made in order to bring together the major “types” of landscape characteristics, for an easier comparison of the simulations produced by the StDM model vs. the real values captured in the field.

After these procedures, a regression analysis (regression model II) was performed to compare the groups of average observed real values of bird densities with the expected values obtained by the model simulations (Standardized Major Axis regression- SMA using the software SMATR 2.0®; Warton et al., 2006). At the end of each analysis, the 95% confidence limits for the intercept and the slope of the regression were determined and allowed us to assess the proximity of the simulations produced with the observed values (Sokal and Rohlf, 1995). The model simulations were considered validated when: (1) the results of the SMA model were statistically significant; (2) the intercept of the common regression line was not statistically different from 0 and; (3) the slope of the regression line was not statistically different from 1 (Sokal and Rohlf, 1995; Oberdorf et al., 2001; Warton et al., 2006).

After the validation process, the model performance was analysed facing realistic scenarios of progressive habitat degradation, in terms of land use and infrastructural changes. The scenarios considered, for the same hypothetical area and based on a possible temporal succession of changes in the region were: (1) an area that changes from extensive agriculture to intensive agriculture and forest; (2) the previous scenario affected also by power lines installation; and (3) the previous scenario affected also by road network developments.

3. Results

3.1. Effects of environmental variables on the males’ density

The resulting little bustard densities varied significantly across the study area, between 0 and 9 males per sampling point (mean = 0.67, S.D. = 1.21).

To test the hypothesis that little bustards avoid the vicinity of high tension power lines, in the context of realistic scenarios, a total of 16 independent variables (Table 1) were considered in the analysis to search the best regression to explain significant relationships between the male’s density and the environmental variables. The regression with the smallest AICc was considered the one that better fitted the data (Table 2). Although other regressions (all possible combinations, 65,535 models, were tested) had close Akaike weights (namely the first 24 which included the 5 variables of the model selected in combination with others), in order to standardize the methodology (Stochastic Dynamic Methodology; Santos and Cabral, 2004) and to reduce subjectivity in the method selection, the equation with the highest AICc wi (parsimonious model) was considered as the one with the best accuracy. The regression model *F*-value and the inspection of each variable significance corroborated this idea (Table 2).

Table 2
The explanatory variables coefficients (Coef), standard error (SE Co), *T*-value (*T*) and significance (*p*) for the best model selected by the AIC criteria (all possible combinations were tested). Model descriptors: degrees of freedom – 933; coefficient of determination – 0.153, Akaike AICc – −263.65, Delta AICc – 0, AICc wi – 0.006 and the *F*-value (ANOVA) – 33.62 ($p < 0.001$). The specification of all variables is available in Table 1.

Variable	Coef	SE Co	*T*	*p*
Constant	0.0378	0.015	2,49	0.013
Log Dist power line	0.954	0.089	10.77	0.000
Log fallow	0.191	0.057	3.32	0.001
Log Montado	−0.486	0.120	−4.05	0.000
Log Forest	−0.648	0.313	−2.07	0.038
Log road	−0.328	0.174	−1.89	0.059

Table 3
Specification of group’s centroids considered for validation. The *k*-means clusters were obtained using Euclidian distances. Values represent the proportion of the different variables, by comparing the obtained values with the maximum figures recorded during the study.

Cluster	Number of observations	Power line dist	Road	Fallow	Montado	Forest
1	8	0.0780	0.0171	0.0064	0.0121	0.0000
2	2	0.0406	0.0843	0.3010	0.0000	0.0000
3	49	0.0816	0.0000	0.2843	0.0118	0.0029
4	29	0.0843	0.0000	0.1654	0.0625	0.0023
5	8	0.0605	0.0000	0.0237	0.2706	0.0000

3.2. Construction of the model and equations

The diagram of the model presented in Fig. 2 is based on the relationships detected in regression analysis (Table 2) and on possible scenarios resulting from the expected evolution of the land uses and socio-economic changes in the studied region (Suárez et al., 1997; De Juana and Martínez, 2001). Therefore, the model includes the following ten state variables, one related to little bustard densities (our indicator) and nine related to environmental variables (land uses) (Fig. 2). For modelling purposes, these environmental variables were adopted as dynamic state variables (Appendix A) based on reliable information about their future tendencies (our scenarios). The explanation of the StDM model, equations and source codes are exposed in Appendices A and B.

3.3. StDM performance and simulations

The five types of “landscapes” considered (estimated from the group’s centroids) contained major gradients of land use and infrastructural characteristics of the region (the k-means result, using the environmental characteristics of each point, is showed in Table 3). The confrontation between the simulated values (males’ density), obtained by the inclusion of the k-means results as environmental variables in the StDM model, and the real ones (captured in the field) is shown in Table 4 and Fig. 4. Table 4 demonstrates that if the Cluster 2 data confrontation (simulated vs. real), which results from an average of just two observations (special areas with very high

Table 4
Results of the Standardized Major Axis regression (SMA) analysis when using all Clusters ($n = 5$) or excluding Cluster 2 ($n = 2$): the coefficient of determination (R^2) and their significance level (n.s. – not significant, *significant). The common line intercepts (95% confidence limits in parenthesis) and difference from 0 verification: *F*-value (n.s. – not significant). The common line slope (95% confidence limits in parenthesis) and difference from 1 verification: *T*-value (n.s. – not significant).

N	R^2	Intercept	*F*-value	Slope	*T*-value
5	0.424 (n.s.)	–	–	–	–
4	0.956*	−0.026 (−0.013; 0.051)	0.529 (n.s.)	1.113 (0.611; 2.028)	−1.459 (n.s.)

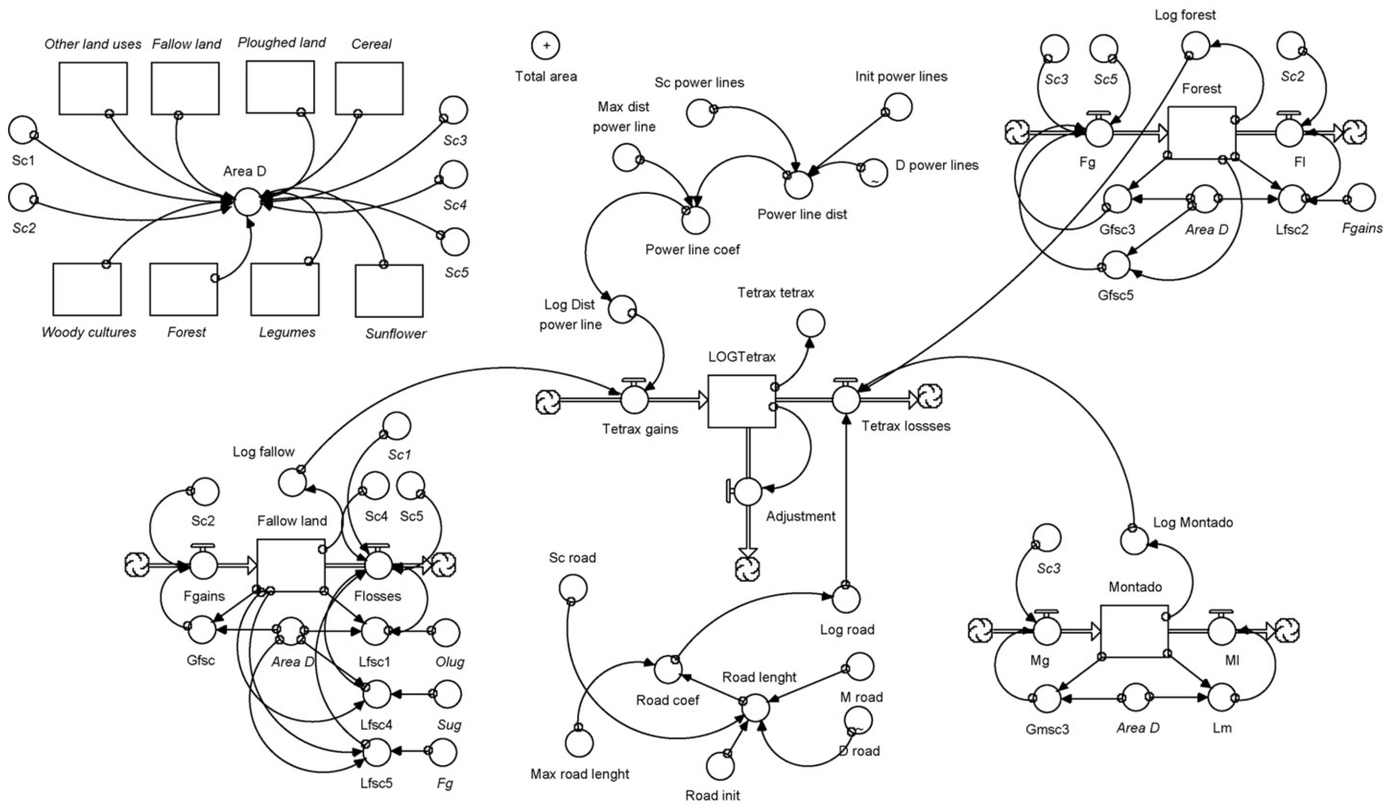

Fig. 2. Conceptual diagram of the model used to predict *Tetrax tetrax* males density in response to land uses and infrastructural changes in a landscape context. Rectangles represent state variables; other variables, parameters or constants are small circles; sinks and sources are cloudlike symbols; flows are thick arrows; all the relations between state variables and other variables are fine arrows. The specification of all variable codes is expressed in Appendix A and Section 3.2.

coverage of fallow, next to power lines and with high density of paved roads), is discarded from the analysis the results of the StDM model simulations are validated (Table 4, second line and Fig. 4).

For the model simulations, the temporal unit chosen was the year (expressed by the respective breeding season), because it was assumed acceptable to monitor the changes that may occur, namely the yearly land use changes and the installation of roads as well as power lines (INE, 2009). The scenarios considered (Figs. 3 and 5) were based on possible temporal transformations that could occur in a sampling point of the studied region, through a simulation period of 10 years. Although the scenarios incorporate changes in many variables, only the selected by the regression (with influence on the *T. tetrax* density) are shown in the results (for a straightforward presentation). The scenario considered, was based on a possible temporal succession of a land use shift from extensive agriculture to intensive agriculture and forest (Fig. 4). The main changes are connected with a decrease in fallow land area (Fallow land; 47–10%), and an increase in the forest area (Forest, 1–20%). The montado area, legally protected, was considered constant during the simulation period (Montado, 5%).

The estimated response of the little bustard densities to the above-described scenario is shown in Fig. 5 by the solid rhombus line. This line illustrates a sharp decrease (−40%) in the little bustard males' density (*T. tetrax*). The solid circles line shows the response to a cumulative scenario that includes additionally a power line installation, in the fifth year, at 2000 m from the centre of the point count

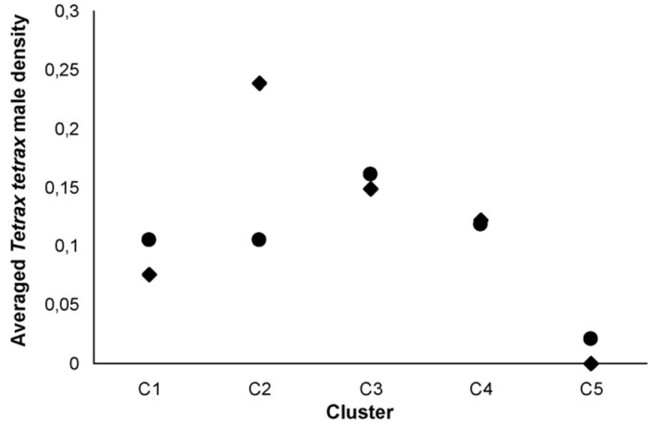

Fig. 3. Graphical comparisons between simulated values produced by model (averaged simulation results, solid circles) and observed values (averaged real values by cluster, solid rhombus), for the little bustard males density.

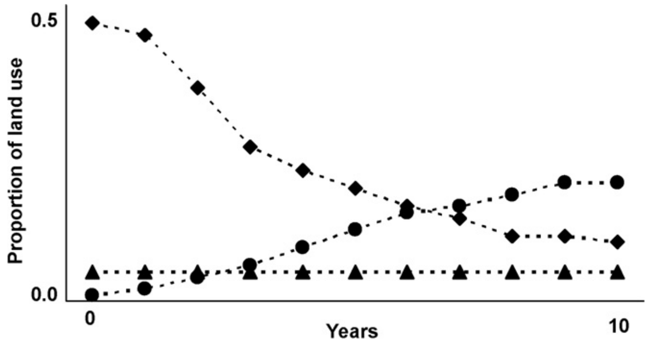

Fig. 4. Illustration of the scenario adopted: for a land use intensification in a point count of the area: (a) solid rhombus line shows the fallow land area reduction; (b) solid circles line shows the forest area increase; (c) solid triangles line shows the montado area maintenance. A simulation period of 10 years was considered.

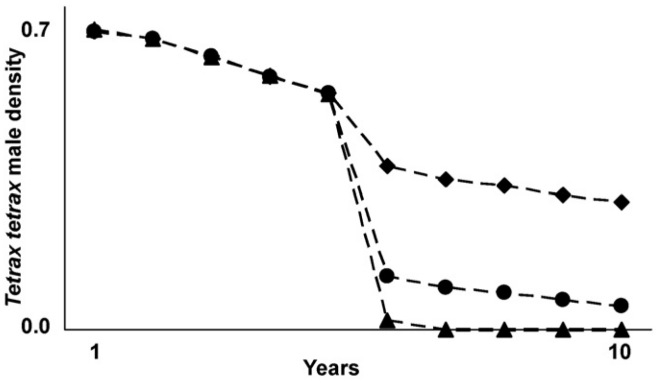

Fig. 5. Response of *Tetrax tetrax* males density to different scenarios of land use change and infrastructural assemblages in a representative point count: (a) solid rhombus line considers merely the response to land use changes described in Fig. 3; (b) solid circles line considers the cumulative response to the previous land use changes with the construction of power lines (in the fifth year, 2000 m from the centre of the point count); (c) solid triangles line shows the cumulative response to the previous scenario with the construction of 200 m of road in the buffer area (in the fifth year).

(Power line dist). In this scenario, the obtained simulation reveals an abrupt decrease (−92%) in males' density (*T. tetrax*), indicating the cumulative effects of land use changes and power line installation. The little bustard density facing the last cumulative scenario (Fig. 5) is represented by the solid triangles line that illustrates a response that also includes the construction of paved roads in the point count area (Road length: 200 m installed in the fifth year of the simulation). In such scenario, regarding density tendencies, a catastrophic reduction will be expected (−100%) in the males' density (*T. tetrax*) with the total abandonment of the local breeding population.

4. Discussion

The factor that most influenced little bustard distribution was the distance to the closest transmission line, meaning that they avoid the vicinity of these utility structures. However, this result should be interpreted in the context of the criteria used to select the study areas, within areas with potential habitat for the occurrence of the little bustard. Nevertheless, the landscape context also played a decisive role as shown by the influence of land use variables also incorporated into the model. In this integrated perspective, our results also corroborate the outcome of previous works, that state that the species selects fallow lands (e.g. Martínez, 1994; Morales et al., 2006) and avoids forest habitats, including montados (Schulz, 1985; Faria and Rabaça, 2004; Moreira et al., 2007), and human active structures, such as roads (Suárez-Seoane et al., 2002; Silva et al., 2004; Osborne and Suárez-Seoane, 2006).

Avoidance of high tension power lines was up to now an unknown factor influencing the little bustard's habitat selection. One probable explanation for this result could be related with disturbance caused by the physical structure itself, since transmission lines can reach up to 60 m high and create a certain discontinuity of the open habitat. This effect has been reported for other open habitat species, such as the common eiders (*Somateria mollissima*), next to wind farms. In this context, the wintering common eiders reduced the frequency of flights and landings within the first 200 m from the structures (up to 60 m high), most likely caused by the physical presence of these structures themselves, rather than the movement and noise of rotors (Larsen and Guilemette, 2007). Disturbance of structures like wind farms were also found to affect passerines, reducing significantly their density in the vicinity of these structures (Leddy et al., 1999; Santos et al., 2010).

On the other hand, overhead towers are likely to increase hunting and harassment pressure caused by predators because of the elevated perches that provide increased visibility for hunting of the surrounding area (Stahlecker, 1978; Graul, 1980; Lammers and Collopy, 2007). This singular effect leads to the avoidance of overhead power lines by three leking grassland birds: the sage-grouse (*Centrocercus urophasianus*, Graul, 1980; Lammers and Collopy, 2007) and both greater and lesser prairie-chickens (*Tympanuchus cupido* and *T. pallidicinctus*, respectively; Pruett et al., 2009).

Most of the little bustard's natural mortality is due to predation (Schulz, 1987). Probably for this reason its behaviour is highly determined by an anti-predatory strategy, with specific habitat requirements, such as preference for hill tops (Silva et al., 2004) or for a particular type of vegetation structure (e.g. Martínez, 1994; Salamolard and Moreau, 1999; Morales et al., 2008), that provide an overall compromise of cover and visibility of approaching predators. Tall overhead poles next to breeding little bustard males are therefore likely to compromise their safety, with higher vulnerability to predation.

Mortality studies carried out along the yearly cycle show that the large majority of collisions with high tension power lines occur outside the breeding season (Neves et al., 2005; Marques et al., 2007), coinciding mostly with seasonal movements. Being such a susceptible species to collide against these infrastructures, this strongly indicates that they avoid their vicinity during the breeding season.

In conclusion, we believe that the strong response of the little bustard to the presence of transmission lines is likely to be directly related to the disturbance caused by the infrastructure itself. If this is the case, then other tall structures such as wind turbines are likely to create a similar effect on the little bustard.

As seen by our modelling procedure, transmission power lines in steppic sites can also contribute to create a cumulative effect with the general tendency towards habitat loss or degradation of breeding habitats, namely by agricultural intensification, abandonment or even forestation (Suárez et al., 1997; De Juana and Martínez, 2001), which can ultimately lead to local abandonment, as demonstrated by our model simulations. This is particularly concerning for those areas where transmission lines already exist within the Beja region, where large irrigation schemes are being implemented as result of the construction of the Alqueva's dam, leading to an overall degradation or even loss of adequate habitat for the breeding little bustards.

With such a strong potential avoidance effect, the transmission power lines are also likely to lead to displacement and habitat fragmentation, limiting the size and density of leks, which might also affecting the reproductive success, since many lek theories predict an increase of reproductive success in larger leks (Höglund and Alatalo, 1995). Further investigation based on detailed continuous spatial data is needed to test this hypothesis.

The StDM model developed in this study can represent a useful contribution for detecting little bustard population changes affected not only by power lines but also by roads and land use developments, namely by quantifying the density variation in different ecological circumstances. In this scope, since the males' density is holistically determined by the habitat structure (Rabin et al., 2006; Fergunson et al., 2008), our StDM simulations allowed for a clear perception of the ecological consequences when these modifications are implemented. This model can also provide a valuable contribution on the elaboration of Strategic Environmental Impact Assessments (SEA) by assessing the cumulative impacts of the overall high tension network on this threatened grassland bird.

These simulation models can be envisaged as a heuristic device useful to test hypothesis about ecological systems under several scenarios. As a result, several researchers have worked on landscape dynamics simulation models, thus contributing to a diversity of approaches (Santos, 2009). Although the StDM is efficient in handling the dynamic behaviour of a system, it is not perceived to be representative of spatial variability within the system. A way to overcome such a negative aspect may be achieved by creating an interface to establish a relationship between the state variable and space (e.g. density vs. distance). Recent advances show that the StDM can be incorporated to a GIS in a format similar to the Dinamica EGO (Soares-Filho et al., 2009; Cabecinha et al., 2009). Studies in this field also aim at the possibility of applying their methods to other areas (Andreasen et al., 2001). In fact, the methodology proposed in this paper is expeditious and easily applicable to systems affected by similar changes. Therefore, we believe that our approach will provide the development of more global techniques in the scope of this research area with the objective of projecting ecosystems' dynamics based on structural simple parsimonious approaches, which will make the methodology more instructive and credible to decision-makers and environmental managers (Bolliger et al., 2005; Cushman et al., 2008).

Based on the results of our study we suggest the following management recommendations: (1) transmission power lines should avoid steppic SPAs with priority breeding little bustard populations because they are liable to affect significantly the conservation values that led to its classification; (2) in steppic SPAs, the dismantling of existing transmission lines should be considered whenever possible; (3) for all new transmission lines planed outside SPAs, crossing steppic areas with breeding little bustard populations, our model should be used as a complementary tool for assessing its impacts and therefore take into account cumulative avoidance effect on breeding populations.

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Appendix A.

Mathematical equations used in Stella for the relationships between male density, roads, power lines and land uses. The specification of variable codes is expressed in Table 1.

Equations

State variable equations

LOGTetrax(t) = LOGTetrax(t – dt) + (Tetrax_gains – Tetrax_lossses – Adjustment) × dt

State variable process equations

LOG Tetrax
INIT LOGTetrax = 0.1506
Tetrax_gains = 0.0378 + 0.954 × Log_Dist_power_line + 0.191 × Log_fallow
Tetrax_lossses = 0.486×Log_Montado + 0.648 × Log_forest + 0.328 × Log_road
Adjustment = LOGTetrax

Complementary state variable

Cereal(t) = Cereal(t – dt) + (Cg – Cl) × dt
Fallow_land(t) = Fallow_land(t – dt) + (Fgains – Flosses) × dt
Forest(t) = Forest(t – dt) + (Fg – Fl) × dt
Legumes(t) = Legumes(t – dt) + (Lg – Ll) × dt
Montado(t) = Montado(t – dt) + (Mg – Ml) × dt
Other_land_uses(t) = Other_land_uses(t – dt) + (Olug – Olul) × dt
Ploughed_land(t) = Ploughed_land(t – dt) + (Plg – Pll) × dt
Sunflower(t) = Sunflower(t – dt) + (Sug – Sul) × dt
Woody_cultures(t) = Woody_cultures(t – dt) + (Wg – Wl) × dt

Complementary state variable process equations

Cereal
INIT Cereal = 0.25
Cg = Gc
Cl = IF Sc1 = 1 THEN Lcsc1 ELSE (IF Sc2 = 1 THEN Lcsc2 ELSE (IF Sc3 = 1 THEN Lcsc3 ELSE (IF Sc4 = 1 THEN Lcsc4 ELSE (IF Sc5 = 1 THEN Lcsc5 ELSE 0))))
Fallow land
INIT Fallow_land = 0.47
Fgains = IF Sc2 = 1 THEN Gfsc ELSE 0
Flosses = IF Sc1 = 1 THEN Lfsc1 ELSE (IF Sc4 = 1 THEN Lfsc4 ELSE (IF Sc5 = 1 THEN Lfsc5 ELSE 0))
Forest
INIT Forest = 0.01
Fg = IF Sc3 = 1 THEN Gfsc3 ELSE (IF Sc5 = 1 THEN Gfsc5 ELSE 0)
Fl = IF Sc2 = 1 THEN Lfsc2 ELSE 0
Legumes
INIT Legumes = 0.01
Lg = Gl
Ll = IF Sc2 = 1 THEN Llsc2 ELSE (IF Sc3 = 1 THEN Llsc3 ELSE (IF Sc5 = 1 THEN Llsc5 ELSE 0))
Montado
INIT Montado = 0.05
Mg = IF Sc3 = 1 THEN Gmsc3 ELSE 0
Ml = Lm
Other land uses
INIT Other_land_uses = 0.06
Olug = IF Sc1 = 1 THEN Golucs1 ELSE 0
Olul = IF Sc2 = 1 THEN Lolusc2 ELSE (IF Sc3 = 1 THEN Lolusc3 ELSE (IF Sc5 = 1 THEN Lolusc5 ELSE 0))
Ploughed land
INIT Ploughed_land = 0.05
Plg = Gpl
Pll = IF Sc2 = 1 THEN Lplsc2 ELSE (IF Sc3 = 1 THEN Lplsc3 ELSE (IF Sc5 = 1 THEN Lplsc5 ELSE 0))
Sunflower
INIT Sunflower = 0.06
Sug = IF Sc4 = 1 THEN Gsusc4 ELSE 0
Sul = IF Sc2 = 1 THEN Lsusc2 ELSE (IF Sc3 = 1 THEN Lsusc3 ELSE (IF Sc5 = 1 THEN Lsusc5 ELSE 0))
Woody cultures
INIT Woody_cultures = 0.04
Wg = Gw
Wl = IF Sc3 = 1 THEN Lwsc3 ELSE 0

Associated variables

Tetrax_tetrax = (10(̂LOGTetrax) – 1)
Log_road = LOG10(Road_coef + 1)
Log_fallow = LOG10(Fallow_land + 1)
Log_forest = LOG10(Forest + 1)
Log_Dist_power_line = LOG10(Power_line_coef + 1)
Log_Montado = LOG10(Montado + 1)

Condition variables

Area_D = IF Sc1 = 1 THEN (Fallow_land + Cereal) ELSE (IF Sc2 = 1 THEN (Forest + Sunflower+ Ploughed_land + Legumes + Other_land_uses + Cereal) ELSE (IF Sc3 = 1 THEN (Woody_cultures + Sunflower + Ploughed_land + Legumes + Other_land_uses + Cereal) ELSE (IF Sc4 = 1 THEN (Fallow_land + Cereal) ELSE (IF Sc5 = 1 THEN (Sunflower + Legumes + Other_land_uses + Fallow_land + Cereal + Ploughed_land) ELSE 0))))
Gc = IF Area_D > 0 AND Area_D>=0 × Cereal THEN 0 × Cereal ELSE (IF Area_D > 0 AND Area_D < 0 × Cereal THEN Area_D ELSE 0)
Gfsc = IF Area_D > 0 AND Area_D>=0.06 × Fallow_land THEN 0.06 × Fallow_land ELSE (IF Area_D > 0 AND Area_D < 0.06 × Fallow_land THEN Area_D ELSE 0)
Gfsc3 = IF Area_D > 0 AND Area_D>=0.5 × Forest THEN 0.5 × Forest ELSE (IF Area_D > 0 AND Area_D < 0.5 × Forest THEN Area_D ELSE 0)
Gfsc5 = IF Area_D > 0 AND Area_D>=0.003 + Forest THEN 0.003 ELSE (IF Area_D > 0 AND Area_D < 0.003 + Forest THEN Area_D ELSE 0)
Gl = IF Area_D > 0 AND Area_D>=0 × Legumes THEN 0 × Legumes ELSE (IF Area_D > 0 AND Area_D < 0 × Legumes THEN Area_D ELSE 0)
Gmsc3 = IF Area_D > 0 AND Area_D>=0.04 × Montado THEN 0.04 × Montado ELSE (IF Area_D > 0 AND Area_D < 0.04 × Montado THEN Area_D ELSE 0)
Golucs1 = IF Area_D > 0 AND Area_D>=0.03 + Other_land_uses THEN 0.03 ELSE (IF Area_D > 0 AND Area_D < 0.03 + Other_land_uses THEN Area_D ELSE 0)
Gpl = IF Area_D > 0 AND Area_D>=0 × Ploughed_land THEN 0 × Ploughed_land ELSE (IF Area_D > 0 AND Area_D < 0 × Ploughed_land THEN Area_D ELSE 0)
Gsusc4 = IF Area_D > 0 AND Area_D>=0.4 × Sunflower THEN 0.4 × Sunflower ELSE (IF Area_D > 0 AND Area_D < 0.4 × Sunflower THEN Area_D ELSE 0)

Gw = IF Area_D > 0 AND Area_D>=0 × Woody_cultures THEN 0 × Woody_cultures ELSE (IF Area_D > 0 AND Area_D < 0 × Woody_cultures THEN Area_D ELSE 0)
Lcsc1 = IF Area_D > 0 AND Cereal<=Area_D THEN (Olug × Cereal/Area_D) ELSE (IF Area_D > 0 AND Olug > Area_D THEN Cereal ELSE 0)
Lcsc2 = IF Area_D > 0 AND Cereal<=Area_D THEN (Fgains × Cereal/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Cereal ELSE 0)
Lcsc3 = IF Area_D > 0 AND Cereal<=Area_D THEN ((Mg + Fg) × Cereal/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Cereal ELSE 0)
Lcsc4 = IF Area_D > 0 AND Cereal<=Area_D THEN (Sug × Cereal/Area_D) ELSE (IF Area_D > 0 AND Sug > Area_D THEN Cereal ELSE 0)
Lcsc5 = IF Area_D > 0 AND Cereal<=Area_D THEN (Fg × Cereal/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Cereal ELSE 0)
Lfsc1 = IF Area_D > 0 AND Fallow_land<=Area_D THEN (Olug × Fallow_land/Area_D) ELSE (IF Area_D > 0 AND Olug > Area_D THEN Fallow_land ELSE 0)
Lfsc2 = IF Area_D > 0 AND Forest<=Area_D THEN (Fgains × Forest/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Forest ELSE 0)
Lfsc4 = IF Area_D > 0 AND Fallow_land<=Area_D THEN (Sug × Fallow_land/Area_D) ELSE (IF Area_D > 0 AND Sug > Area_D THEN Fallow_land ELSE 0)
Lfsc5 = IF Area_D > 0 AND Fallow_land<=Area_D THEN (Fg × Fallow_land/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Fallow_land ELSE 0)
Llsc2 = IF Area_D > 0 AND Legumes<=Area_D THEN (Fgains × Legumes/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Legumes ELSE 0)
Llsc3 = IF Area_D > 0 AND Legumes<=Area_D THEN ((Mg + Fg) × Legumes/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Legumes ELSE 0)
Llsc5 = IF Area_D > 0 AND Legumes<=Area_D THEN (Fg × Legumes/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Legumes ELSE 0)
Lm = IF Area_D > 0 AND Montado<=Area_D THEN (0 × Montado/Area_D) ELSE (IF Area_D > 0 AND 0 × Montado > Area_D THEN Montado × 0 ELSE 0)
Lolusc2 = IF Area_D > 0 AND Other_land_uses<=Area_D THEN (Fgains × Other_land_uses/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Other_land_uses ELSE 0)
Lolusc3 = IF Area_D > 0 AND Other_land_uses<=Area_D THEN ((Mg + Fg) × Other_land_uses/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Other_land_uses ELSE 0)
Lolusc5 = IF Area_D > 0 AND Other_land_uses<=Area_D THEN (Fg × Other_land_uses/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Other_land_uses ELSE 0)
Lplsc2 = IF Area_D > 0 AND Ploughed_land<=Area_D THEN (Fgains × Ploughed_land/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Ploughed_land ELSE 0)
Lplsc3 = IF Area_D > 0 AND Ploughed_land<=Area_D THEN ((Mg + Fg) × Ploughed_land/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Ploughed_land ELSE 0)
Lplsc5 = IF Area_D > 0 AND Ploughed_land<=Area_D THEN (Fg × Ploughed_land/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Ploughed_land ELSE 0)
Lsusc2 = IF Area_D > 0 AND Sunflower<=Area_D THEN (Fgains × Sunflower/Area_D) ELSE (IF Area_D > 0 AND Fgains > Area_D THEN Sunflower ELSE 0)
Lsusc3 = IF Area_D > 0 AND Sunflower<=Area_D THEN ((Mg + Fg) × Sunflower/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Sunflower ELSE 0)
Lsusc5 = IF Area_D > 0 AND Sunflower<=Area_D THEN (Fg × Sunflower/Area_D) ELSE (IF Area_D > 0 AND Fg > Area_D THEN Sunflower ELSE 0)
Lwsc3 = IF Area_D > 0 AND Woody_cultures<=Area_D THEN ((Mg + Fg) × Woody_cultures/Area_D) ELSE (IF Area_D > 0 AND (Mg + Fg) > Area_D THEN Woody_cultures ELSE 0)
Power_line_coef = IF Max_dist__power_line > 0 then Power_line_dist/Max_dist__power_line else 0
Power_line_dist = IF Sc_power_lines = 0 THEN Init_power_lines ELSE (IF Sc_power_lines = 1 THEN Cuba_power_line ELSE (IF Sc_power_lines = 2 THEN M_power_lines ELSE (IF Sc_power_lines = 3 THEN D_power_lines ELSE (IF Sc_power_lines = 4 THEN A_power_lines ELSE 0))))
Road_coef = Road_lenght/Max_road_lenght
Road_lenght = IF Sc_road = 0 THEN Road_init ELSE (IF Sc_road = 1 THEN M_road ELSE (IF Sc_road = 2 THEN A_road ELSE (IF Sc_road = 3 THEN D_road ELSE (IF Sc_road = 4 THEN Cuba_road ELSE 0))))

Composed variables

Total_area = Woody_cultures + Sunflower + Forest + Other_land_uses + Ploughed_land + Legumes + Montado + Fallow_land + Cereal

Constants

Sc1 = 0
Sc2 = 0
Sc3 = 0
Sc4 = 0
Sc5 = 0
Sc_power_lines = 3
Sc_road = 2
Road_init = 0
Max_dist__power_line = 21190.07
Max_road_lenght = 645.51
M_power_lines = 6018.14
M_road = 15.68
Cuba_road = 6.64
Init_power_lines = 21190.0667

Table functions

A_power_lines = GRAPH(TIME)
(0.00, 6018), (1.00, 6018), (2.00, 6018), (3.00, 12000), (4.00, 12000), (5.00, 12000), (6.00, 12000), (7.00, 12000), (8.00, 18000), (9.00, 18000), (10.0, 18000)
A_road = GRAPH(time)
(1.00, 15.7), (2.00, 15.7), (3.00, 64.6), (4.00, 64.6), (5.00, 64.6), (6.00, 194), (7.00, 194), (8.00, 194), (9.00, 387), (10.0, 387)
Cuba_power_line = GRAPH(Time)
(0.00, 15837), (1.00, 15837), (2.00, 15837), (3.00, 15837), (4.00, 15837), (5.00, 15837), (6.00, 3650), (7.00, 3650), (8.00, 3650), (9.00, 3650), (10.0, 3650), (11.0, 3650), (12.0, 3650)
D_power_lines = GRAPH(TIME)
(0.00, 6018), (1.00, 6018), (2.00, 6018), (3.00, 3000), (4.00, 3000), (5.00, 3000), (6.00, 3000), (7.00, 1000), (8.00, 1000), (9.00, 1000), (10.0, 1000)
D_road = GRAPH(TIME)
(1.00, 15.7), (2.00, 15.7), (3.00, 15.7), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00)

Appendix B.

4.1. Model explanation

The basic unit of our StDM model is the state variable of the little bustard densities (LOGTetrax) (Fig. 2), described by difference equations (Appendix A – difference equations). The inflow (*Tetrax* gains) affecting this state variable was based on positive constants and all positive partial coefficients resulting from the previous regression analysis (Table 2, Fig. 2, Appendix A – difference and process equations). On the other hand, the outflow (*Tetrax* losses) was related to the negative constants and partial regression coefficients influences (Table 2, Fig. 2, Appendix A – difference and process equations). Although the output for the state variable (LOGTetrax) simulated is composed of a given value per time unit, the respective state variable could have a cumulating behaviour over time in response to changes in the environmental conditions. Thus, to avoid this, an additional outflow adjustment was incorporated in the state variable (Adjustment). This outflow adjustment aimed to empty the state variables in each time step, by a "flushing cistern" mechanism, before beginning the next step with new environmental influences (Fig. 2 and Appendix A – difference and process equations).

For process compatibilities and a more realistic comprehension of the model simulations, some conversions were introduced, denominated associated variables (Fig. 2 and Appendix A – associated variables). These conversions were obtained through an inverse transformation (anti-logarithmic), which transforms logarithms into the original measurement units of little bustard densities (*T. tetrax*). Other variables, resulting from simple mathematical operations between variables (e.g. total area; Fig. 2 and Appendix A – composed variables), were used to complete and control the output of the model and named composed variables. The environmental variables were logarithm transformed for a compatible integration in the balances of the little bustard state variable (Fig. 2 and Appendix A – associated variables). These transformations (e.g. Log Montado) were incorporated because the data required for the state variable balances should have the same units used to obtain the partial regression coefficients, assumed as holistic ecological parameters (see Section 2). Therefore, only logarithms of the environmental variables are acceptable in the inflow and outflow of the state variable used for little bustard density estimations (Fig. 2 and Appendix A – difference equations and process equations). Therefore, the model is prepared to accept and transform real data from the environmental variables and to convert logarithmic outputs from specific passerine estimation back into the original units.

Other important variables for the landscape context, such as the complementary state variables (e.g. Cereal), the condition variables (e.g. Area D) and constants (e.g. Sc1) were used to implement land use dynamics in the model scenarios, logical resolutions and deterministic patterns (Fig. 2 and Appendix A – complementary state variables, other variables and constants).

References

Andreasen, J.K., O'Neill, R.V., Noss, R., Slosser, N.C., 2001. Considerations for the development of a terrestrial index of ecological integrity. Ecol. Indic. 1, 21–35.

Akaike, H., 1974. A new look at the statistical model identification. Autom. Control, IEEE Trans. 19, 716–723.

Anderson, D., Burnham, K., Thompson, W., 2000. Null hypothesis testing: problems. Prevalence Altern. J. Wildl. Manage. 64, 912–923.

Ballasus, H., Sossinka, R., 1997. The impact of power lines on field selection and grazing intensity of wintering White-fronted and *Gean Geese Anser albifrons*, *A. Fabalis*. J. Ornithol. 138, 215–227.

Baudry, J., Burel, F., Thenail, C., Le Cœur, D., 2000. A holistic landscape ecological study of the interactions between farming activities and ecological patterns in Brittany, France. Lands Urban Plan 50, 119–128.

Bavenger, K., 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biol. Conserv. 86, 67–76.

BirdLife International 2009. Species facsheet Tetrax tetrax. In: IUCN 2009. IUCN Red List of Threatened Species, Available from: www.birdlife.org, as posted on 26.4.2010.

Bolliger, J., Lischke, H., Green, D.G., 2005. Simulating the spatial and temporal dynamics of landscapes using generic and complex models. Ecol. Complex 2, 107–116.

Cabecinha, E., Pardal, M.A., Cortes, R., Cabral, J.A., 2009. A Stochastic Dynamic Methodology (StDM) for reservoir's water quality management: validation of a multi-scale approach in a south European basin (Douro Portugal). Ecol. Indic. 9, 329–345.

Cabral, J.A., Cabecinha, E., Santos, M., Travassos, P., Silva-Santos, P., 2008. Simulating the ecological status of changed ecosystems by holistic applications of a new Stochastic Dynamic Methodology (StDM). In: Alonso, M.S., Rubio, I.M. (Eds.), Ecological Management, New Research. NovaScience Publishers, New York, pp. 123–141.

Costa, L.T., Nunes, M. Geraldes, P., Costa, H., 2003. Zonas Importantes para as Aves em Portugal. Sociedade Portuguesa para o Estudo das Aves.

Cushman, S.A., McGarigal, K., Nell, M.C., 2008. Parsimony in landscape metrics: strength, universality, and consistency. Ecol. Indic. 8, 691–703.

De Juana, E., Martínez, C., 2001. Little bustard (*Tetrax tetrax*). In: Schaffer, N., Gallo-Orsi, U. (Eds.), European Union Action Plans for Eight Priority Bird Species. European Commission, Luxemburg, pp. 1–17.

Falster, DS, Warton, DI, Wright, I.J., 2006. SMATR: Standardised Major Axis Tests and Routines, Ver 2.0, Available from: http://www.bio.mq.edu.au/ecology/SMATR/, as posted on 21.03.2010.

Faria, N., Rabaça, J., 2004. Breeding habitat modelling of the Little Bustard *Tetrax tetrax* in the Site of Community Importance of Cabrela (Portugal). Ardeola 51, 331–343.

Fergunson, C.A., Carvalho, L., Scott, E.M., Bowman, A.W., Kirika, A., 2008. Assessing ecological responses to environmental change using statistical models. J. Appl. Ecol. 45, 193–203.

Goriup, P., 1994. Little Bustard *Tetrax tetrax*. In: Tucker, G.M., Heath, M.F. (Eds.), Birds in Europe: their Conservation Status. BirdLife International, Cambridge, pp. 236–237.

Graul, W.D., 1980. Grassland management and bird communities. In: DeGraff, R.M., Tilghman, N.G. (Eds.), Management of Western Forests and Grasslands for Nongame Birds. U. S. Forest Service, Utah, pp. 38–47.

Höglund, J., Alatalo, R.V., 1995. Leks. Princeton University Press, Princeton, New Jersey.

Hurvich, C., Tsai, C., 1989. Regression and time series model in small samples. Biometrika 76, 297–307.

INE – Instituto Nacional de Estatística. Available from: http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main, as posted on 18.9.2009.

Janss, G.F.E., 2000. Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biol. Conserv. 95, 353–359.

Jiguet, F., Bretagnolle, V., 2001. Courtship behaviour in a lekking species: individual variations and settlement tactics in male little bustard. Behav Proc 55, 107–118.

Lammers, W.M., Collopy, M.W., 2007. Effectiveness of avian predator perch deterrents on electric transmission lines. J. Wildl. Manage. 71, 2752–2758.

Larsen, J.K., Guilemette, M., 2007. Effects of wind turbines on flight behaviour of wintering eiders: implications for habitat use and collision risk. J. Appl. Ecol. 44, 516–522.

Leddy, K.L., Higgins, K.F., Naugle, D.E., 1999. Effects of wind turbines on upland nesting birds in conservation reserve program grasslands. Wilson Bull. 111, 100–104.

MacQueen, J.B., 1967. Some methods for classification and analysis of multivariate observations. In: Proceedings of 5th Berkeley Symposium on Mathematical Statistics and Probability, vol. 1, Berkeley, Univ. Calif. Press, pp. 281–297.

Marques, AT, Rocha, P, Silva, J.P., 2007. Monitoring the Effects of a Very High Tension Power Line on Great Bustards, Mortality and Flight Frequencies. Instituto da Conservação da Natureza, Available from: http://portal.icnb.pt/NR/rdonlyres/31B631BE-D753-4EEC-8AFC8D9E37477689/0/Rel_Fin_REN_MonitAltaTensao_Ferreira_jun07.pdf, as posted on: 15.01.2010.

Martínez, C., 1994. Habitat selection by the Little Bustard *Tetrax tetrax* in cultivated areas of Central Spain. Biol. Conserv. 67, 125–128.

Morales, M.B., Traba, J., Delgado, M.P., García de la Morena, E., 2008. Sexual differences in microhabitat selection of breeding little bustards *Tetrax tetrax*: ecological segregation based on vegetation structure. Acta Oecol. 34, 345–353.

Morales, M.B., Suárez, F., García de La Morena, E., 2006. Reponses des oiseaux de steppe aux differents niveaux de mise en culture et d'intensification du paysage agricole: une analyse comparative de leurs effets sur la densite de population et la selection de l'habitat chez l'outarde canepetiere *Tetrax tetrax* et l'outarde barbue Otis tarda. Rev. Ecol. (Terre et Vie) 61, 261–270.

Moreira, F., Leitão, P.J., Morgado, R., Alcazar, R., Cardoso, A., Carrapato, C., Delgado, A., Geraldes, P., Gordinho, L., Henriques, I., Lecoq, M., Leitão, D., Marques, A.T., Pedroso, R., Prego, I., Reino, L., Rocha, P., Tomé, R., Osborne, P.E., 2007. Spatial distribuition patterns, habitat correlates and population estimates of steppe birds in Castro Verde. Airo 17, 5–30.

Naveh, Z., 1998. From biodiversity to ecodiversity—holistic conservation of the biological and cultural diversity of Mediterranean landscapes. In: Rundel, P.W., Montenegro, G., Jaksic, F.M. (Eds.), Landscape Degradation and biodiversity in Mediterranean-Type Ecosystems, Ecological Studies, vol. 136. Springler-Verlag, New York, pp. 23–53.

Neves, J, Infante, S, Ministro, J., 2005. Impacts of Very High Tension Power Lines on Birds in Portugal. Sociedade Portuguesa para o Estudo das Aves and Quercus Associação Nacional de Conservação da Natureza, Available from: http://www.centrodeinformacao.ren.pt/PT/publicacoes/PublicacoesGerais/Protocolo%20REN-ICN.pdf, as posted on 01.15.2010.

Oberdorf, T., Pont, D., Hugheny, B., Chessel, D., 2001. A probabilistic model characterizing fish assemblages of French rivers: a framework for environmental assessment. Freshw. Biol. 46, 399–415.

Osborne, E.P., Suárez-Seoane, S., 2006. Identifying core areas in a species range using temporal suitability analysis: an example using little bustards *Tetrax tetrax* L. Biodivers. Conserv. 16, 3505–3518 (in Spain).

Plumpton, D.L., Andersen, D.E., 1997. Habitat use and time budgeting by wintering ferruginous hawks. Condor 99, 888–893.

Pruett, C.L., Patten, M.A., Wolfe, D.H., 2009. Avoidance behaviour by Prairy Grouse: implications for development of wind energy. Conserv. Biol. 23, 1253–1259.

Rabin, L.A., Coss, R.G., Owings, D.H., 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). Conserv. Biol. 131, 410–420.

REN – Rede Eléctrica de Portugal, 2008. Characterizing the National Transmission Network, Available from: http://www.ren.pt, as posted on: 4.1.2010.

Rangel, T.F.L., Diniz-Filho, J.A.F., Bini, L.M., 2006. Towards and integrated computational tool for spatial analysis in macroecology and biogeography. Glob. Ecol. Biogeogr. 15, 321–327.

Salamolard, M., Moreau, C., 1999. Habitat selection by Little Bustard Tetrax tetrax in a cultivated area of France. Bird Study 46, 25–33.

Santos, M., 2009. Simplifying Complexity: Applications of Stochastic Dynamic Methodology (StDM) in Terrestrial Ecology. PhD Thesis. University of Trás-os-Montes e Alto Douro.

Santos, M., Cabral, J.A., 2004. Development of a stochastic dynamic model for ecological indicators prediction in changed Mediterranean agroecosytems of north-eastern Portugal. Ecol. Indic. 3, 285–303.

Santos, M., Vaz, C., Travassos, P., Cabral, J.A., 2007. Simulating the impact of socio-economic trends on threatened Iberian wolf populations Canis lupus signatus in north-eastern Portugal. Ecol. Indic. 7, 649–664.

Santos, M., Bastos, R., Travassos, P., Bessa, R., Repas, M., Cabral, J.A., 2010. Predicting the trends of vertebrate species richness as a response to wind farms installation in mountain ecosystems of northwest Portugal. Ecol. Indic. 10, 192–205.

Schulz, H., 1985. Grundlagenforschung zur Biologie der Zwergtrappe *Tetrax tetrax*. Braunschweig. PhD thesis. Staatlichen Naturhistorischen Museum, Braunschweig, Germany.

Schulz, H., 1987. Biologie et protection de L'Outarde Canepetiere *Tetrax tetrax*. Faune de Provence (CEEP) 8, 54–78.

Silva, J.P., Pinto, M., Palmeirim, J.M., 2004. Managing landscapes for little bustard *Tetrax tetrax*: lessons from the study of winter habitat selection. Biol. Conserv. 117, 521–528.

Silva, J.P., Leitão, D., Santos, E., Moreira, F., Prego, I., Pinto, M., Lecoq, M., Catry, T., Pedroso, R., 2006. Preliminary results of the Little Bustard's census in Alentejo (Portugal). In: Leitão, D., Jolivet, C., Rodriguez, M., Tavares, J. (Eds.), Bustard Conservation in Europe in the Last 15 Years: Current Trends, Best Practice and Future Priorities. RSPB/BirdLife, Bedfordshire, pp. 55–59.

Soares-Filho, B.S., Rodrigues, H.O., Costa, W.L.S., 2009. Modeling Environmental Dynamics with Dinamica EGO. Centro de Sensoriamento Remoto/Universidade Federal de Minas Gerais.

Sokal, R.R., Rohlf, F.J., 1995. Biometry, 3rd ed. WH Freeman and Company, New York.

Stahlecker, D.W., 1978. Effect of a new transmission power line on wintering prairie raptors. Condor 80, 444–446.

Suárez, F., Naveso, M.A., De Juana, E., 1997. Farming in the drylands of Spain: birds of the pseudosteppes. In: Pain, D.J., Pienkowski, M.W. (Eds.), Farming and Birds in Europe. The Common Agricultural Policy and its Implication for Bird Conservation. Academic Press, London, pp. 297–330.

Suárez-Seoane, S., Osborne, P.E., Alonso, J.C., 2002. Large-scale habitat selection by agricultural steppe birds in Spain: identifying species-habitat responses using generalized additive models. J. Appl. Ecol. 39, 755–771.

Zar, J.H., 1996. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, NJ.

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