Development of a stochastic dynamic model for ecological indicators’ prediction in changed Mediterranean agroecosystems of north-eastern Portugal

Mário Santos a, Pedro Santos b, João Alexandre Cabral c

a Laboratory of Applied Ecology, Department of Environmental and Biological Engineering, Universidade de Trás-os-Montes e Alto Douro, 5000-911 Vila Real, Portugal, mgsantos@utad.pt

b Laboratory of Applied Ecology, Department of Environmental and Biological Engineering, Universidade de Trás-os-Montes e Alto Douro, 5000-911 Vila Real, Portugal, psantoss@utad.pt

c Laboratory of Applied Ecology, Department of Environmental and Biological Engineering, Universidade de Trás-os-Montes e Alto Douro, 5000-911 Vila Real, Portugal, jcabral@utad.pt

Abstract

A holistic stochastic dynamic model was developed by focusing on the interactions between conceptually isolated key components, such as local passerine guilds and changes in habitat conditions, in Mediterranean agroecosystems of the “Terra Quente Transmontana region” (north-eastern Portugal). The ecological integrity of the typical patchwork of this region, with respect to land use, can be partly assessed by the observation of the occurrence of passerine guilds. These important indicators and state variables are the underlying database of our model. This model aimed the prediction of the ecological changes which can be expected when olive orchards are being intensified. The model proposed was preceded by a conventional multivariate statistical procedure (stepwise multiple regression analysis) performed to discriminate the significant relationships between guild richness and environmental variables. Since this statistical analysis is static, the dataset recorded from the field included true gradients of habitat changes. The model parameters were estimated from the results of the stochastic treatment and from regional data regarding tendencies within the use of land. A period of 50 years was considered. The final model provided some basis to analyse the responses of passerine guilds to the environmental scenarios that will characterize the new agroecosystems of the region. The model simulations were incorporated into a Geographical Information System (GIS) approach. The results of the simulation revealed a structural drift within the different guild richness in response to the expected gradient of habitat changes. The possible local extinction of several species within the less well-represented guilds, such as the steppe passerine species, may be associated with a predictable reduction in ecological integrity of the typical agroecosystems. Therefore, a new structure of the passerine communities indicates that future agroecosystems will diverge from the initial or actual ecological state.

Key words: Olive orchards; Mediterranean agroecosystems; Ecological integrity indicators; Passerine functional guilds; Stochastic dynamic model

1 Introduction

The Mediterranean region has evolved over thousands of years with an increasing role played by human activity (Ribeiro, 1987; Naveh, 1998). For many species of wildlife, little of their original habitat remains and for many centuries they have adapted in order to exploit landscapes that have been shaped by human activity (Pain, 1994; Naveh, 1998; Bignal and McCracken, 2000). Olive (Olea europaea) production forms a significant land use in this region with important environmental, social and economic implications (EC, 1997). The European Common Agriculture Policy (CAP) is changing the traditional pattern agriculture and the landscape by encouraging farmers of the European Union (EU) to plant intensive modern plantations, marginalising agroecosystems such as winter cereals, extensively grazed
pastures and low-input olive farming (Naveh, 1998; Beaufoy, 2001; Stoate et al., in press). For conservation and management purposes, the use of adequate ecological integrity indicators is particularly helpful in assessing the impact of land use changes on characteristic ecological patterns (Romstad, 1999; Medellín et al., 2000; Müller et al., 2000; Andreasen et al., 2001; Dale and Beyeler, 2001; Welsh Jr. and Droge, 2001). According to Dale and Beyeler (2001) the selection of ecological indicators requires some predefined criteria. Passerine functional guilds present several characteristics that have justified this choice. One of the great challenges in ecological integrity studies is to predict how anthropogenic environmental changes will affect the abundance of species, guilds or communities in disturbed ecosystems (Kareiva et al., 1993; Andreasen et al., 2001). Although ecological models have been used for predicting bird species responses to environmental stresses and landscape characteristics, most of them are static (e.g. Beard et al., 1999; Manel et al., 1999; Baillie et al., 2000; Carroll and Pearson, 2000; Fewster et al., 2000; Manel et al., 2001). Static models with fixed parameters are unable to estimate the structural changes when the habitat conditions are substantially changed (Jørgensen and Bernardi, 1997). Therefore, it is a goal of ecological modelling to construct dynamic models and structural dynamic models that adequately attempt to capture the structure and the composition, including the related processes, in those systems (Jørgensen, 1989; Jørgensen, 1994; Chaloupka, 2002). In fact, the dynamic models are very important tools with which to improve the assessment of the medium-long-term directional environmental disturbances (Jørgensen, 1989). These are, for instance, the impacts resulting from the development of new types of agricultural practices (Cabral et al., 2001). The application of ecological modelling is able to synthesize the pieces of ecological knowledge, emphasizing the need for an holistic view of a certain environmental problem (Mitsch and Jørgensen, 1989). With this idea in mind, the main objective of the present paper was to develop an holistic predictive approach, by using appropriate statistical and modelling techniques, to assess the ecologic impact of the progressive substitution of the traditional agricultural pattern by intensive olive farming in Mediterranean agroecosystems. Therefore, it was a goal of this work to construct a stochastic dynamic model by focusing on the interactions between conceptually isolated key-components in such systems, namely between local breeding passerine guilds and environmental conditions.

2. Methods

2.1. Study area

The study was conducted near the town of Mirandela (41° 30’ N, 7°10’ W), in two areas (A and B) of the Terra Quente Transmontana region, north-eastern Portugal (fig. 1). A typical mixture of olive orchards, cereal fields, fallow land, cistus sp. shrublands, cytisus sp. shrublands, cork oak woodlands and almond orchards dominates the landscape. The main agricultural changes are the steep decrease in the amount of cereal and fallow land and the growth of areas occupied by intensive olive orchards and forests (RGA, 1992; RGA, 1999).

Fig 1. Location of the study areas in North-eastern Portugal. Area A has 2500 ha undergoing drastic agricultural changes (100 plots), and area B has 2500 ha dominated by olive orchards (100 plots).
2.2 Passerine and habitat surveys

The plots were surveyed every two weeks between mid-February and the end of July of 2001. The breeding season was chosen for this study according to the assumption that passerines would be more dependent upon a restricted landscape and resources. One 10 minute unlimited-radius point count (Ralph et al., 1993) was done by plot and surveys were conducted until five hours after sunrise, a period when most passerines were active. Habitat was described at the end of each point count. In the olive orchard, canopy height, tree perimeter, canopy cover and density of trees were measured as close as possible more to the centre of the plot (Bibby et al., 1992). Ground cover was registered. All the olive orchards in each plot were measured as a percentage of area and classified into four age class groups (Michelakis et al., 1994; Guerrero, 1997). The passerine species whose feeding habits and/or habitat requirements were not directly dependent on vegetation structure were excluded from the data analysis (e.g. Corvidae, Hirundinidae). The combination of the information regarding habitat requirements and foraging habits enabled us to establish four categories of guilds: (1) arboreal insectivorous, (2) arboreal granivorous, (3) pseudo-steppe insectivorous and (4) pseudo-steppe granivorous. A stepwise multiple regression analysis (Zar, 1984) was used to test for relationships between dependent and environmental variables. The dependent variables correspond to the guilds composition, in number of species, also called guild richness (Gaston and Blackburn, 2000). The independent variables were the proportion of area occupied by the principal land uses considered. A step down procedure was used so that the effect of each variable in the presence of all others could be examined first with the least significant variable being removed at every step. The analysis stopped when all the surviving variables had a significance level < 0.05 (Zar, 1984). The lack of substantial intercorrelation among independent variables was assured by the inspection of the respective tolerance values. All the statistical analyses were carried out using the software SYSTAT 8.0®. Since the previous statistical procedures were based on data sets that include true gradients of agroecosystem changes, over space and time, the significant partial regression coefficients were assumed as relevant holistic ecological parameters in the dynamic model construction. This is the heart of the philosophy of the stochastic dynamic model developed. This model does not distinguish between different species within the guilds selected, but considers them as a whole in each correspondent state variable. Therefore, in an holistic perspective, the partial regression coefficients represent the global influence of the environmental variables selected that are of significant importance on several complex ecological processes not included explicitly in the model, but related with the state variables, or guilds, under consideration. The information regarding the historical landscape dynamics was obtained from national data (RGA, 1992; RGA, 1999) and personal communications by regional agro-technicians. To develop this model we used STELLA 5.0®. The output of the model simulations was thereafter incorporated in a GIS conception for better visualisation and understanding of the ecological pattern of guilds occurrence, through time, under the environmental changes anticipated for area A. In this case, a direct correspondence between each plot and each pixel was adopted.

3. Results

3.1 General results

We recorded 53 passerine species throughout the 6 months of the census program. The distribution of passerine species per guild allowed as to identify 24 arboreal insectivorous, 9 arboreal granivorous, 12 pseudo-steppe insectivorous and 8 pseudo-steppe granivorous.

3.2 Conceptualisation of the model, equations and simulations

The diagram of the model is based on the relationships detected in the multiple regression analysis, on existing regional data sets for relevant environmental variables regarding agriculture dynamics in the region (RGA, 1992; RGA, 1999), and on possible scenarios resulting from EU funds influencing this agriculture dynamics (EC, 1997). Therefore, the model includes the following nineteen state variables: four related to the functional guilds and fifteen related to the expansible/retractile environmental variables measured. Difference equations that describe the processes affecting the state variables are expressed in a logarithm of richness for the functional guilds and in proportion to the occupied area for the environmental variables (Difference equations). The initial values of all state variables (Process equations), were based on the average data recorded in area A between February and July 2001, i.e. from
the breeding season of 2001, in a representative average plot of area A. The responses to habitat changes of each passerine guild richness for the entire area A, i.e. for all plots assumed as pixels in a GIS format, can be observed, with more particularity, in Figure 3 for 25 and 50 years. The same general model runs in each pixel. Individual pixel models are initialised according to the environmental variables and guilds’ richness recorded in each plot. Taking into consideration passerine richness as a whole, Figure 2 shows that the spatial component of the model developed produces significant spatio-temporal variability in estimated richness with clear divergences from the initial values. Overall, every pixel simulation reproduces quite well the guild’s behaviour empirically noticed for the representative average plot of area A in which we can observe a step increase in arboreal groups and a decrease in pseudo-steppe groups as the expected agriculture changes occur.

Fig. 2. Predicted changes for all plots in area A (each one with 25 ha) produced by model simulations, per pixel in a GIS format representation, for periods of 25 and 50 years. Total Olive - proportion of area occupied by olive orchards as a whole; Arb Ins sp - arboreal insectivorous richness; Arb Gran sp - arboreal granivorous richness; Pse Ste Insect sp - pseudo-steppe insectivorous richness; Pse Ste Gran sp - pseudo-steppe granivorous richness.

4. Discussion

The model developed in this study seems to make a useful contribution to the assessment of the ecological integrity of typical Mediterranean agroecosystems affected by the increasing area of intensive olive plantations. In fact, the simulation results showed that the functional guilds selected, as state variables, were not indifferent to the structural changes expected to occur in the studied agroecosystems. The relevant ecological drifts observed are in agreement with other studies that investigated the biological consequences of agroecosystem changes and of these types of agricultural practices on characteristic faunal groups in general and on bird richness in particular (e.g. Rey et al., 1997; Haagen et al., 2000; Siriwardena et al., 2000; Söderström and Pärt, 2000). Moreover, the simulation results reflect well the agroecosystem shift towards new expected conditions, with possible detrimental effects on the traditional landscape characteristics and pseudo-steppe passerine occurrence. If we consider that mixed agroecosystems are among the richest habitats of the Mediterranean region (Bignal and McCracken, 2000) and that many species with a high conservation value are present in with pseudo-steppe farming systems, then the simulation results can give rise to some concerns. Considering that CAP (Common Agriculture Policy) will not change substantially in the next years, and that almost all Northern Mediterranean Countries are, or will be, regulated by this policy, then the region will probably lose many of its characteristic species and the ecological integrity of the traditional farming patchwork will be reduced. In fact, the growth of intensified olive farming is one of the major causes of land use changes and environmental problems in Mediterranean countries (Beaufoy, 2001). Another goal when developing methods for assessing changes in the ecological integrity of agroecosystems is the feasibility of application and extent to which the results can be reproduced in other areas (Andreassen et al., 2001).
fact, the methodology is expeditious and easily applicable to several agroecosystems affected by structural changes. The previous multivariate statistical analysis gives robustness to the dynamic interactions connected during the model construction. Another advantage is the compatible integration as an interface with GIS, which makes the model more instructive and credible to the decision-makers and environmental managers (Costanza, 1992). Nevertheless, if we consider that validation is a fundamental process when showing the relative accuracy of the model response in relation to its applicability (Rykiel, 1996) then two main questions remain within the present methodology. The first one deals with the impracticality of an immediate validation, which can only be done after several years of collecting relevant site specific information (Glenz et al., 2001) and the second one regards the demographic stochasticity of bird communities that was impossible to account for in one year of field work (Chaloupka, 2002).

5. References


